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LESSER SLAVE LAKE

SEDIMENTATION STUDY

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LESSER SLAVE LAKE

SEDIMENTATION STUDY

Submitted to:

Alberta Environment
Edmonton, Alberta

Submitted by:

AMEC Earth & Environmental,
a division of AMEC Americas Limited
Calgary, Alberta

March 2005

CW1902

EXECUTIVE SUMMARY

Lesser Slave Lake is the third largest lake in Alberta. The principal channels flowing into the lake are East Prairie River, West Prairie and South Heart River, Swan River and Driftpile River. The lake has a single outlet to Lesser Slave River. This study was undertaken to determine current sediment inflows to the lake, assess the sources of sediment, and determine the impacts of sedimentation on the lake.

Sediment in the Lesser Slave Lake watershed is produced by three major mechanisms. These are:

- sediment resulting from "natural" processes such as downcutting of the channels resulting from post-glaciation lowering of Lesser Slave Lake approximately 11,000 years ago as well as from soil erosion from undisturbed lands;
- sediment resulting from the response of the river channels to man-made flood control, erosion control and river training works; i.e. bank protection, channelization, grade control and flood protection dyking projects. These works were constructed between the 1950's and the 1980's, primarily in the East Prairie, West Prairie and South Heart River channels; and
- sediment resulting from the land use changes and altered runoff characteristics in the watershed. These include lands that have been cleared and disturbed for agriculture, roads, oil and gas exploration and development, forestry and settlement in the Lesser Slave Lake watershed .

The relative contributions of each of the above mechanisms to the total sediment load produced in the watershed can only be answered qualitatively.

Available historical channel cross-section surveys for the principal channels were compared to assess trends in channel bed level changes and channel size over time. The survey database contained gaps that limited the conclusions that could be made based on the available data, and did not provide sufficient detail to determine whether channel degradation and aggradation rates are increasing, remaining the same or declining from the levels assessed in previous investigation.

The areas of man-made disturbances in each of the watersheds have increased over the past five decades. The total disturbed land area in the East Prairie River basin is now 17 times what it was 50 years ago, and in the West Prairie River watershed, the present area of disturbed land is 30 times the area of disturbance 50 years ago. Although the increased sediment loads resulting from land disturbance can not be quantified, sediment yields from disturbed lands have increased. Sediment loads as a result of natural channel processes may have decreased as a result of possible upstream extension of the zone affected by channel modifications. It is uncertain whether the sediment loads resulting from channel modifications have increased, remained the same or decreased since the time of the most recent previous studies (undertaken in the mid-1980's).

Sediment inflows to the lake are estimated on the basis of historical recorded streamflow data and rating curves relating suspended sediment concentrations to stream discharge. Much of the total sediment load (approximately 85%) from the East Prairie, West Prairie and South Heart Rivers is deposited upstream of Lesser Slave Lake. The three channels flow across a flat plains area at the west end of the lake that reduces channel slopes and the sediment carrying capacity of the channels. The resulting deposition has resulted in reduced channel capacities and increased incidences of overbank flooding. The West Prairie and South Heart Rivers flow through Horse Lakes and Buffalo Bay; deposition in these two areas has contributed to significant delta growth and reduced the total sediment input to Lesser Slave Lake. In the Swan and Driftpile Rivers, virtually all of the sediment conveyed by the two rivers is carried onto the respective deltas areas in Lesser Slave Lake.

A sediment balance was prepared for Lesser Slave Lake, using the estimated sediment inflows from the five principal channels and from the ungauged area draining to Lesser Slave Lake. The total net annual sediment input to Lesser Slave Lake was estimated to be approximately 1,170,000 tonnes. The amount deposited in the Buffalo Bay/Horse Lakes area by the East Prairie, West Prairie and South Heart Rivers was estimated to be 1,100,000 tonnes per year. Sediment output from the lake was estimated using trap efficiency curves. At least 97% of the inflowing sediment is estimated to settle in Lesser Slave Lake. Hence, the annual sediment output from the lake to Lesser Slave River is approximately 36,000 tonnes.

There are insufficient data to allow a quantitative comparison between present and historical rates of sedimentation, as there are limited suspended sediment data available in the tributary watersheds for the period of 1983 to 1997 and no data available since 1997. Qualitatively, development within the watersheds is believed to be increasing the sediment generated within the basins, primarily in those basins on the south side of the lake. Changes to the alignments of the South Heart and East Prairie river channels have altered the water and sediment flows into Buffalo Bay. Sediment delivery to Buffalo Bay has been reduced from pre-1984 levels primarily due to the late 1980's diversion of East Prairie River.

The available data are not sufficient to determine whether channel changes as a result of man-made activities are ongoing, to what extent land use changes in the watersheds are affecting sediment loads in the channels, or how the estimated annual sediment loads are apportioned between "natural" sources, manmade channel changes and land use changes.

Over time, the impacts of man-made channel modifications upstream of the lake will be attenuated as the rivers approach regime conditions; this will reduce sediment inputs to the channels. This reduction in sediment input will be offset to some degree by increased sediment loading as a result of land use changes. Because the present distribution of sediment based on origin can not be well established, it is not possible to project future sedimentation rates to Lesser Slave Lake. Based on present rates of sedimentation, however, it would take many hundreds of years for sedimentation to significantly impact Lesser Slave Lake and approximately 10,000 years for Lesser Slave Lake to be filled with sediment.

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TABLE OF CONTENTS

PAGE

1.0 INTRODUCTION 1
1.1 Lesser Slave Lake Watershed 1
1.2 Objectives 1

2.0 HYDROLOGY 3
2.1 Available Data 3
2.2 Data Assessment and Results 4

3.0 SEDIMENT SOURCES AND TRANSPORT 7
3.1 Geomorphology of Principal Tributary Channels 7
3.2 Vertical and Lateral Channel Movement 8
3.2.1 Specific Gauge Curves 8
3.2.2 Comparative Surveys 11
3.2.3 Sediment Generated by Bed Degradation and Bank Erosion 14

4.0 SEDIMENT LOADS 15
4.1 Available Data 15
4.2 Annual Total Sediment Loads 16
4.2.1 Sediment Rating Curves 16
4.2.2 Sediment Loads 18
4.3 Lesser Slave Lake Sediment Budget 20

5.0 SEDIMENT DEPOSITION 23
5.1 Historical Air Photo Interpretation 23
5.2 Visible Areas of Sediment Deposition and Delta Growth 24
5.3 Littoral Transport 29

6.0 EFFECTS OF ENGINEERING WORKS ON SEDIMENT PRODUCTION AND TRANSPORT 30
6.1 Description of Constructed Engineering Works 30
6.1.1 East Prairie River 30
6.1.2 West Prairie River and Lower South Heart River 31
6.1.3 South Heart River Upstream of West Prairie River 31
6.1.4 Swan River 31
6.1.5 Driftpile River 31
6.2 Channel Changes Since Implementation of Engineering Works 32
6.3 Comparison with Estimated Natural Channel Changes 33

7.0 EFFECTS OF LAND USE ACTIVITIES ON SEDIMENT PRODUCTION 34
7.1 Land Use Changes in the Lesser Slave Lake Watershed 34
7.2 Estimated Impacts of Land Use Changes on Sediment Production 35

8.0 SUMMARY AND CONCLUSIONS 37

9.0 REFERENCES 40

LIST OF TABLES

Table 1 WSC Streamflow Monitoring Stations 3
Table 2 Mean and Total Annual Discharges 4
Table 3 Discharges Used for Specific Gauge Curve Development 9
Table 4 Summary of Survey Data Available for Present Study 11
Table 5 Sediment Monitoring Stations in the Lesser Slave Lake Watershed 15
Table 6 Annual Total Suspended Sediment Loads 18
Table 7 Comparison of Annual Suspended Sediment Loads with Previous Estimates 18
Table 8 Average Annual Total Sediment Loads 20
Table 9 Lesser Slave Lake Sediment Budget 22
Table 10 Delta Slopes and Rates of Growth 29
Table 11 Volumetric Changes in East Prairie River 32
Table 12 Volumetric Changes in West Prairie and South Heart Rivers 33
Table 13 2003 Land Use Areas in Sub Basins 34
Table 14 Soil Loss for Various Land Uses 35

LIST OF FIGURES

Figure 1 Lesser Slave Lake Basin 2
Figure 2 Historical Annual Total Discharges for Lesser Slave Lake Tributary Channels 5
Figure 3 Flow Duration Curves, East Prairie and West Prairie Rivers 6
Figure 4 Specific Gauge Curves 10
Figure 5 Channel Thalweg Profiles 12
Figure 6 Sediment Rating Curves 17
Figure 7 Annual Total Suspended Sediment Load 19
Figure 8 South Heart/West Prairie River Delta (Buffalo Bay) 25
Figure 9 Swan River Delta 26
Figure 10 Driftpile River Delta 27
Figure 11 Lesser Slave Lake Outlet to Lesser Slave River 28
Figure 12 Land Use Changes Within the East and West Prairie Drainage Basins 36

APPENDICES

Appendix A Bias Correction Factor

1.0 INTRODUCTION

Alberta Environment (AENV) and the Lesser Slave Lake Watershed Committee are currently preparing a water management plan for the Lesser Slave River and lake basins. Phase 1 of the water management plan is focussing on the Lesser Slave River and the development of water conservation objectives for the river. Future phases of the plan will focus on Lesser Slave Lake and its tributaries. This report is intended to provide background information on sedimentation processes in Lesser Slave Lake that have been identified in public meetings as a significant issue for the lake.

1.1 Lesser Slave Lake Watershed

Lesser Slave Lake, located in north-central Alberta approximately 250 km northwest of Edmonton, is the third largest lake in Alberta. The lake has a drainage area of approximately 13 600 km^2, with most of its inflow originating in the Swan Hills area to the south of the lake. The main channels flowing into Lesser Slave Lake are the East Prairie, West Prairie, South Heart, Swan and Driftpile Rivers. The lake also has numerous smaller tributary channels and a single outlet to the Lesser Slave River, as shown in Figure 1.

Lesser Slave Lake has three discrete basins: Buffalo Bay, and the east and west basins of the main body of the lake. Buffalo Bay is located at the northwest end of the lake and receives flows from the West Prairie and South Heart Rivers. Historically, the East Prairie also flowed into Buffalo Bay. After the 1988 flood, the East Prairie River was diverted into an existing channel and presently flows directly into the channel connecting Buffalo Bay with Lesser Slave Lake, just upstream of the Grouard causeway. The main body of Lesser Slave Lake is separated at the Narrows into east and west basins. Buffalo Bay and the Driftpile River drain into the west basin of the main body of Lesser Slave Lake. The Swan River drains into the east basin. A fixed crest weir located approximately 1.5 kilometres downstream of the lake outlet and seven channel cut-offs on the Lesser Slave River downstream of the weir have reduced lake level fluctuation by 0.8 metres.

1.2 Objectives

Sedimentation in Lesser Slave Lake is perceived by the public to be an issue. Specifically, attention has focused on perceived increased rates of sediment transport into the lake and accelerated delta formation. Sedimentation upstream of the weir at the lake outlet resulting from littoral sediment transport and lakeshore erosion has periodically reduced the capacity of the Lesser Slave River channel and recently led to channel dredging in 1999.

Alberta Environment retained AMEC Earth & Environmental, a division of AMEC Americas Limited (AMEC), to conduct a review of sedimentation in Lesser Slave Lake. The objectives of the study were to:

- review and summarize all available information, including existing studies, maps, air photos and sediment/hydrometric data for the Lesser Slave Lake basin;

Legend

- ▲ WSC Sediment Sampling and Streamflow Monitoring Location
- □ AENV Sediment Sampling Location
- Regional Drainage Sub-Basin Boundary

Lesser Slave Lake Drainage Sub-Basins

- Lesser Slave Lake Drainage Basin Boundary
- Driftpile River Sub-Basin
- East Prairie River Sub-Basin
- South Heart River Sub-Basin
- Swan River Sub-Basin
- West Prairie River Sub-Basin
- Other Drainage Sub-Basin

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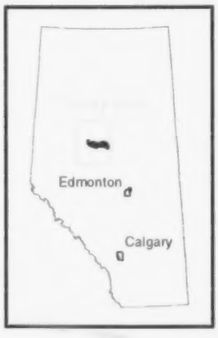
2003 IRS Mosaic



CLIENT: Alberta Environment

PROJECT: **Lesser Slave Lake Sedimentation Study**

Lesser Slave Lake Drainage Basins

DATE	PROJECTION	DATUM
February, 2005	UTM Zone 11	NAD83
JOB No. DATE: CW1902		
GIS FILE: LSL_WatershedPlan_v2		
PDF FILE: LSL_watershed_05-02-24		

Figure 1

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6
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7
9
10
5
Grouard Mission
West Prairie River
near High Prairie
2
4
1
East Prairie River
near Enilda
High
Prairie
Enilda
Driftpile River near Driftpile
Kinuso
Swan River near Kinuso
Faust
Lesser Slave Lake
at Slave Lake
Slave Lake
Lesser Slave River
at HWY 2A
Adams Creek near Kinuso
3
11
Swan Hills

Legend

- WSC Sediment Sampling and Streamflow Monitoring Location
- AENV Sediment Sampling Location
- Regional Drainage Sub Basin Boundary

Lesser Slave Lake Drainage Sub-Basins

- Lesser Slave Lake Drainage Basin Boundary
- Driftpile River Sub Basin
- East Prairie River Sub Basin
- South Heart River Sub Basin
- Swan River Sub Basin
- West Prairie River Sub Basin
- Other Drainage Sub Basin

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ARC/INFO Mosaic

Alberta Environment

Lesser Slave Lake Sedimentation Study

Lesser Slave Lake Drainage Basins

February 2000 | UTM Zone 11 | NAD83
CW1420
LSL WatershedPlan_v2
LSL watershed 05-02-24

Figure 1

- document current conditions in Lesser Slave Lake and assess the sediment transport processes in the lake and its tributary channels. This assessment is to be based on existing data;
- report on existing conditions and sedimentation in the lake; and
- identify data gaps and develop a work program for future field studies and data analysis to provide sufficient data to fully address the questions regarding sedimentation in Lesser Slave Lake.

2.0 HYDROLOGY

2.1 Available Data

The Water Survey of Canada (WSC) and Alberta Environment have operated streamflow monitoring stations on all of the principal tributaries to Lesser Slave Lake, as shown in Figure 1. Data gathered by Alberta Environment comprises mainly miscellaneous streamflow measurements, while the WSC records include continuous records of daily streamflow. Recorded streamflow data were obtained for the WSC stations listed in Table 1.

TABLE 1
WSC Streamflow Monitoring Stations

Station	Station Name	Period of Record (1)	Operation (2)	Drainage Area (km^2)
07BF001	East Prairie River near Enilda	1921 – 1931 1959 – 2004	Seasonal	1,460
07BF002	West Prairie River near High Prairie	1921 – 1931 1959 – 2004	Seasonal to 1970. Annual since 1970.	1,160
07BF004	South Heart River near High Prairie	1921 – 1930	Seasonal	4,240
07BF009	Salt Creek near Grouard	1986 – 2004	Seasonal	426
07BF010	South Heart River near Peavine	2000 – 2004	Seasonal	
07BH003	Driftpile River near Driftpile	1972 – 1986	Seasonal	840
07BJ001	Swan River near Kinuso	1915 – 1917 1961 – 2004	Seasonal to 1970. Annual since 1970.	1,900
07BK009	Sawridge Creek near Slave Lake	1976 – 2004	Seasonal	233
07BK001	Lesser Slave River at Slave Lake	1915 – 1940 1960 – 2004	Annual	13,600

(1) Data available for operating stations to the end of 2003 only.

(2) Annual operation entails data collection from January to December. Seasonal operation comprises a truncated monitoring season, typically from March or April to October.

Hydrologic estimates are contained in many of the reports previously prepared for projects or assessments within the Lesser Slave Lake basin, including NHCL (1984), Alberta Environment (1977a), Hardy (1989) and others.

2.2 Data Assessment and Results

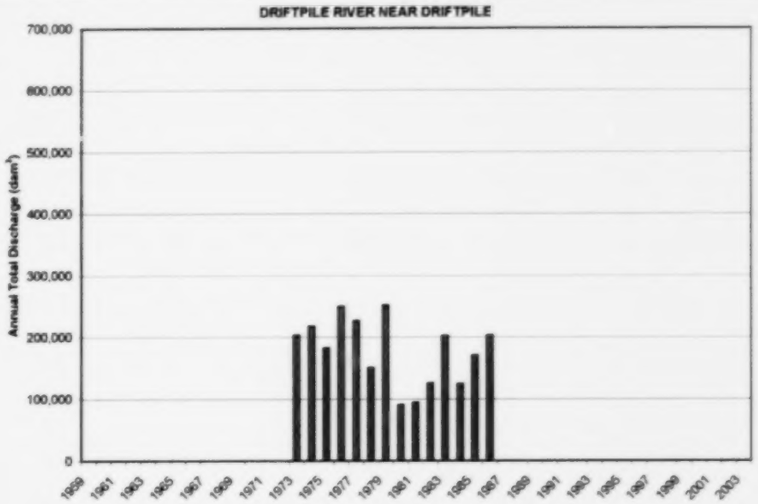
Mean discharges were computed for the available period of record to 2003 for the stations listed in Table 1. Annual mean discharges were computed for stations with year-round data, and seasonal mean discharges for those stations with seasonal data. These results are summarized in Table 2.

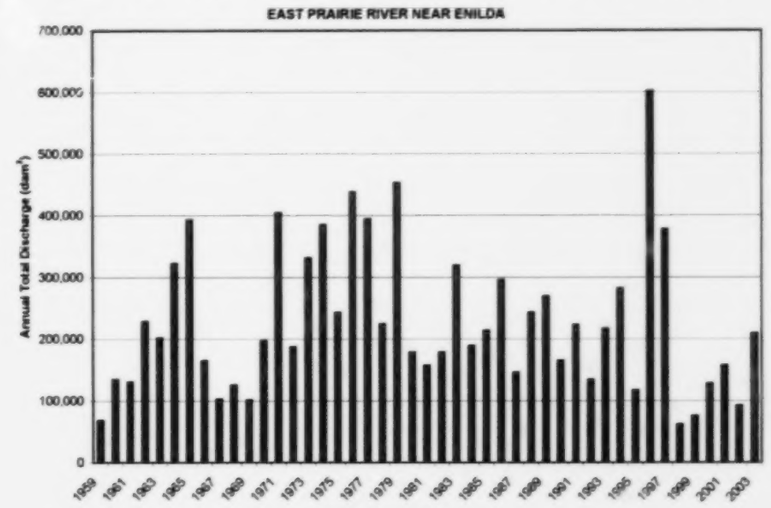
TABLE 2
Mean and Total Annual Discharges

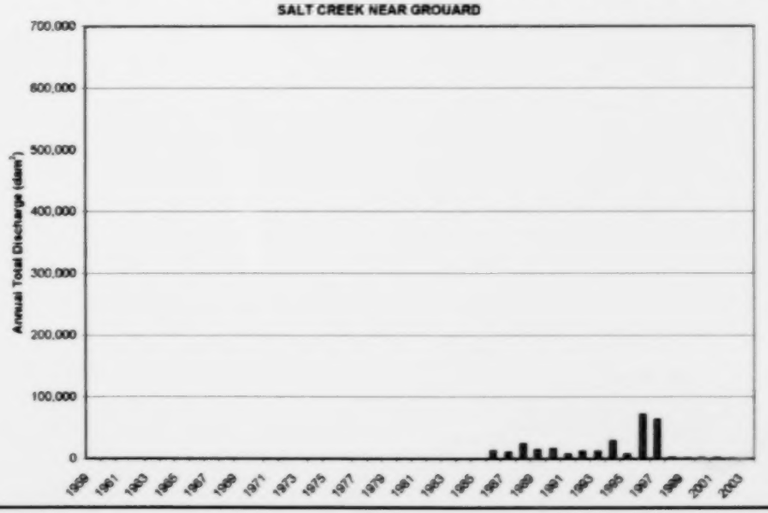
Station No.	Station Name	Mean Discharge (m^3/s)	Average Total Discharge (dam^3)
07BF001	East Prairie River near Enilda	10.8	228,100
07BF002	West Prairie River near High Prairie	4.58	144,400
07BF009	Salt Creek near Grouard	0.82	17,300
07BF010	South Heart River near Peavine	0.47	9,860
07BH003	Driftpile River near Driftpile	8.42	166,300
07BJ001	Swan River near Kinuso	13.1	413,200
07BK009	Sawridge Creek near Slave Lake	2.29	48,320
07BK001	Lesser Slave River at Slave Lake	38.0	1,197,300

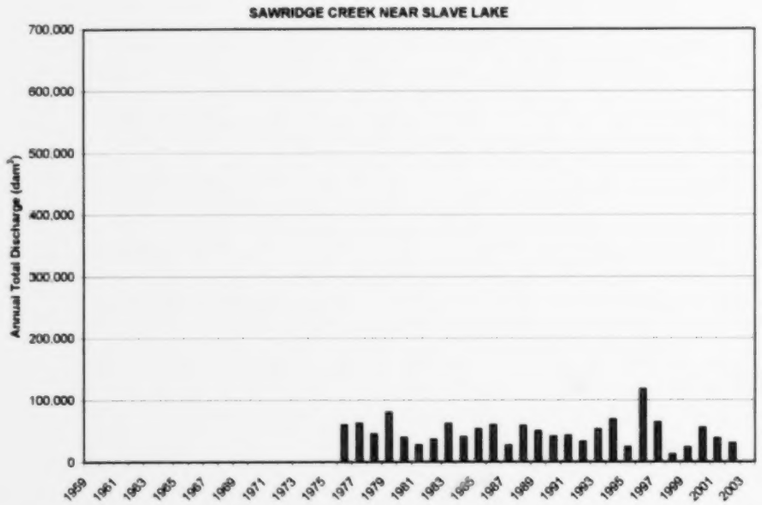
Historical seasonal and annual total discharges at each of the stations listed in Table 2 are presented in Figure 2 to demonstrate the relative contribution of each basin to total inflows to Lesser Slave Lake.

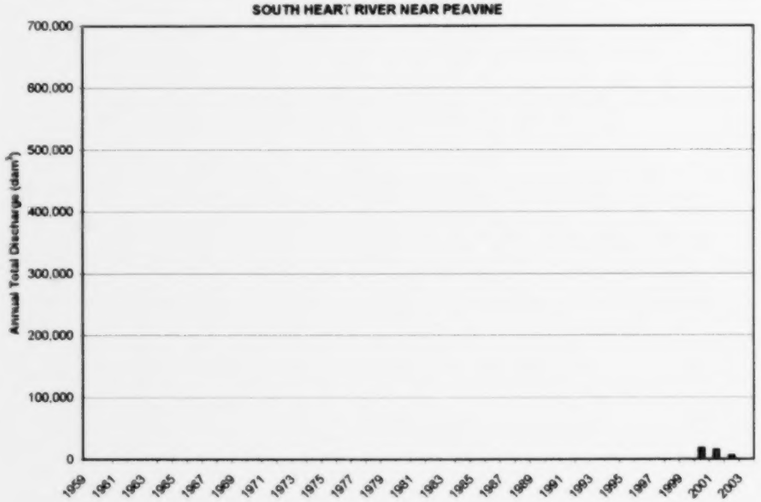
Flow duration curves were prepared using mean daily discharge data from the East Prairie River (07BF001) and West Prairie River (07BF002) stations for the period of record (1921 to 2000). The flow duration curves for the two stations are presented in Figure 3.

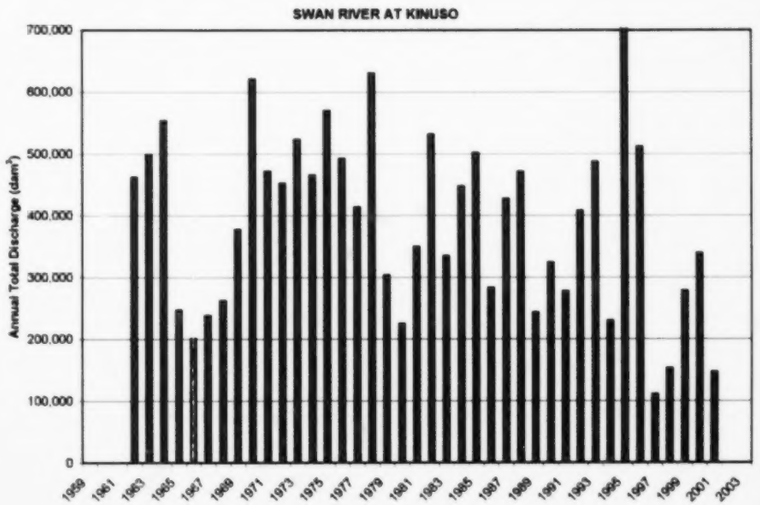


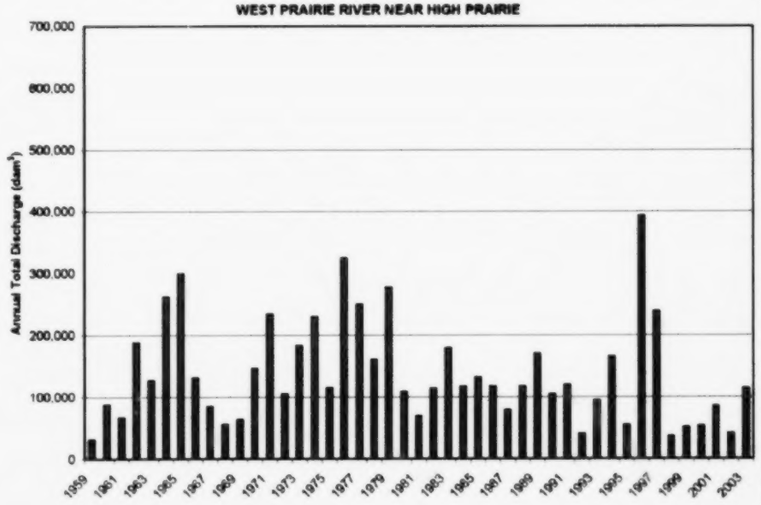












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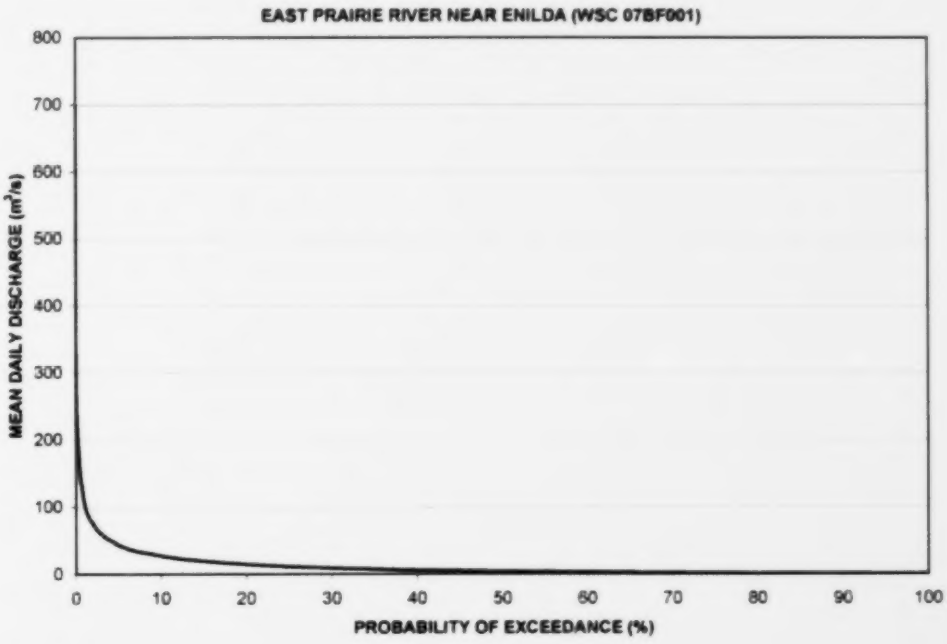
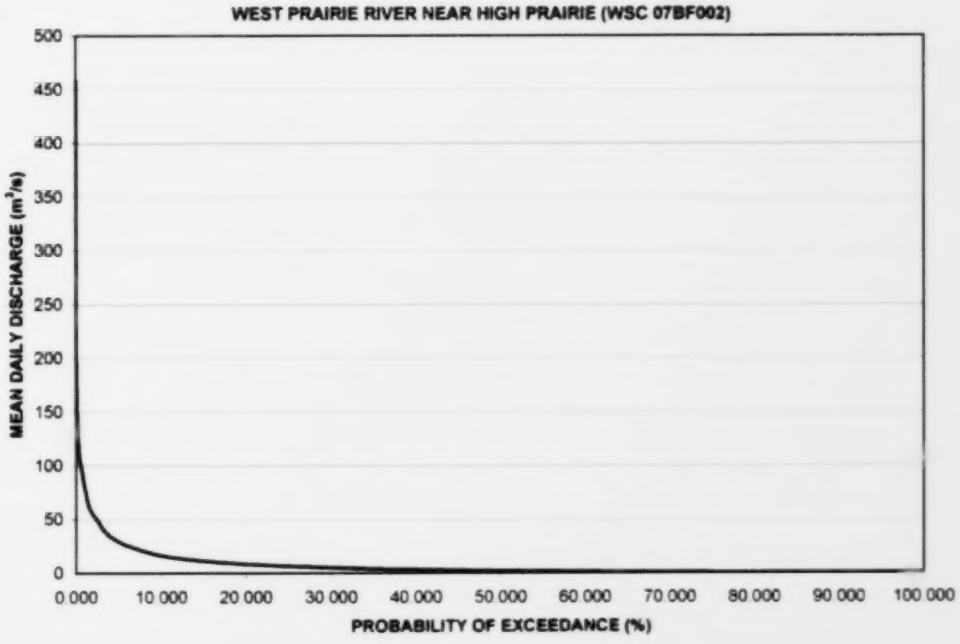
CLIENT: ALBERTA ENVIRONMENT

PROJECT: LESSER SLAVE LAKE SEDIMENT STUDY

TITLE: HISTORICAL ANNUAL TOTAL DISCHARGES LESSER SLAVE LAKE TRIBUTARIES

DATE:	JOB No.:	CAD FILE:	FIGURE No.:	REV.
MARCH 2005	CW1902	1902-S00.dwg	FIGURE 2	A





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CLIENT: ALBERTA ENVIRONMENT

PROJECT: LESSER SLAVE LAKE SEDIMENT STUDY

TITLE: FLOW DURATION CURVES
EAST PRAIRIE AND WEST PRAIRIE RIVERS

DATE	JOB No.	CAD FILE	FIGURE No.	REV.
MARCH 2005	CW1902	1902-S00.dwg	FIGURE 3	A

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3.0 SEDIMENT SOURCES AND TRANSPORT

3.1 Geomorphology of Principal Tributary Channels

The surficial geology and geomorphology of the Lesser Slave Lake basin, and in particular the western portion of the basin drained by the East Prairie, West Prairie and South Heart Rivers, have been discussed in detail by previous researchers, including Mollard (NHCL, 1983). The following two paragraphs provide a synopsis of the discussion presented by Mollard.

A proglacial lake formed in the region of present-day Lesser Slave Lake approximately 11,500 years ago. Till deposited in the lake forms the base for alluvial and deltaic materials deposited between Elevation 625 masl (metres above sea level) and 577 masl (roughly the elevation of the present-day Lesser Slave Lake). Meltwater from the receding glacier flowed south and southwest along the South Heart River channel, resulting in the formation of a large sand and gravel delta southeast of Winagami Lake; the delta deposits become progressively finer to the southeast, with fine to medium sand in the vicinity of the South Heart/West Prairie River confluence.

Initial draining of the glacial lake from 625 to 577 masl resulted in downcutting of the South Heart, West Prairie and East Prairie River channels. As the rivers downcut, alluvial material was deposited downstream. Mollard hypothesizes that surface deposits above Elevation 579 masl are likely alluvial in origin, comprising stratified silts and fine sands with some clay. These deposits overlie "heavier textured, less easily eroded glacial lake tills and silty clays" located generally below 579 masl. The underlying materials are noted to become coarser in the upstream direction towards the confluence of the South Heart and West Prairie Rivers and along the main stems of the South Heart, West Prairie and East Prairie Rivers.

The Swan Hills area, headwaters for the West Prairie, East Prairie, Driftpile and Swan Rivers, has a peak elevation of approximately 1,250 masl. These four river channels all have two distinct reaches: a steep upper reach on the flanks of the Swan Hills, and a flatter lower reach as the channel crosses the plain south of Lesser Slave Lake. Channel slopes in the order of 0.003 to 0.025 are reported for the upper reaches of the East and West Prairie Rivers; channel slopes in the flatter downstream reaches of these two channels are in the order of 0.0006 (Hydrocon, 1984).

The upper reaches of the principal channels draining to Lesser Slave Lake have high sediment carrying capacities by virtue of their slopes and flow velocities. As the rivers transition into their lower reaches on the much flatter plain adjacent to the lake, channel slopes and consequently sediment carrying capacities are significantly reduced, resulting in deposition within the channels, channel aggradation, overbank flow (flooding) and levee building.

The rivers have a long history of conveying high sediment and debris loads (Hydrocon, 1984). Correspondence dating from as early as 1914 describes frequent debris jamming events, principally on the East Prairie and West Prairie Rivers, and records from 1932 describe ongoing channel degradation and channel widening at the old Highway 2 crossing of East Prairie River.

Mollard reports that in the early 1950's the West Prairie River below High Prairie and the East Prairie River below Enilda changed from large single channels with well-defined valleys to "a maze of small indistinct channels threading through a swampy depression", likely as a result of log or ice jams. Human activity in these watersheds (primarily agriculture and logging) could have contributed to these channel changes through increased sediment and debris loading and decreased hydrological response times. The Swan and Driftpile Rivers, however, continue to occupy well-defined single channels despite undergoing much similar watershed development.

The primary difference between the East Prairie/West Prairie/South Heart Rivers and the Swan River is the change in bed slope near the mouth. Based on survey data gathered between 1978 and 1981, the bed gradient of the Swan River increases from approximately 0.003 m/m upstream to 0.007 m/m near the mouth, whereas the bed slope of the West Prairie/South Heart River decreases from approximately 0.006 m/m upstream to 0.002 m/m near the historic confluence with the East Prairie River. Similarly, the bed slope of the East Prairie River decreases from approximately 0.006 m/m upstream to approximately 0.004 m/m near the historic confluence with the West Prairie/South Heart River. Note that these bed slopes are based on surveys dating from the early 1990's in both channels. No survey data are available for the Driftpile River. The increase in bed slope in the lower reaches of the Swan River increases the sediment-carrying capacity of the channel and allows sediment to be conveyed out onto the river delta.

The downcutting of the East Prairie, West Prairie, Swan and Driftpile Rivers has been the natural response of the channels to the 50 metre base level change resulting from draining of the proglacial lake some 11,000 years ago. Although recent (since the mid-1960's) human interventions in the channels, principally the East Prairie and West Prairie Rivers, have locally increased channel erosion, the processes of channel downcutting and sediment transport/ sediment deposition and delta formation in Buffalo Bay and Lesser Slave Lake have been ongoing for many thousands of years.

3.2 Vertical and Lateral Channel Movement

3.2.1 Specific Gauge Curves

Specific gauge curves present gauge height, or water level, for a specific discharge over a period of time. With sufficient data, specific gauge curves can identify and help to quantify the processes of channel aggradation or degradation over time. The data required to develop a specific gauge curve include rating curves for a specific streamflow-gauging site over an extended period of record and information on any changes in gauge location or elevation of the station datum. For this study, the Water Survey of Canada provided historical rating curves for their streamflow monitoring stations on the East Prairie, West Prairie, Swan and Driftpile Rivers. Using the average annual discharges for each channel, gauge heights were extracted from the respective rating curves over the available period of record. The average annual discharges used to develop the specific gauge curves at each of the stations are summarized in Table 3.

TABLE 3
Discharges Used for Specific Gauge Curve Development

Station No.	WSC Station Name	Mean Discharge (m^3/s) for Period of Record to 2000
07BF001	East Prairie River near Enilda	7.5
07BF002	West Prairie River near High Prairie	4.8
07BF009	Salt Creek near Grouard	0.61
07BH003	Driftpile River near Driftpile	5.8
07BJ001	Swan River near Kinuso	13.5
07BK009	Sawridge Creek near Lesser Slave Lake	1.6

Gauge histories were used to convert the gauge heights to elevations (geodetic or assumed, depending on the gauge datum). It was found that the streamflow monitoring stations have been disturbed or moved relatively frequently on all the subject channels except the Driftpile River. Hence, determinations of long-term trends in channel bed elevations was, in some cases, limited by the truncated periods of record continuous to a single gauging site on a given channel. The derived specific gauge curves are presented in Figure 4.

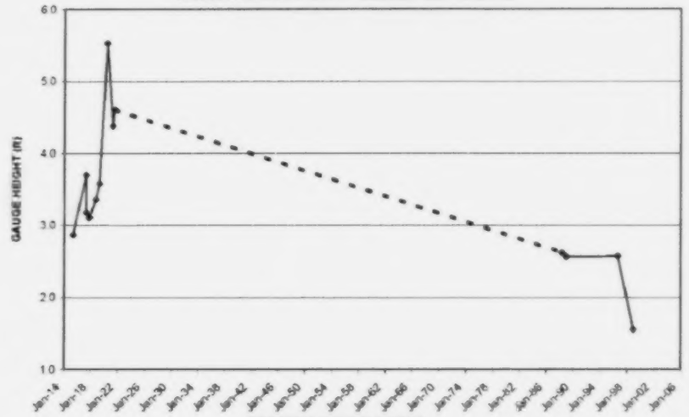
The specific gauge curve for the East Prairie River near Enilda shows a period of rapid channel degradation between 1960 and 1977 (water levels declined 5.4 metres over 17 years, or 0.32 metres/year). Since 1976, channel degradation has continued but at a much slower rate (water levels have declined 0.4 metres over 20 years, or 0.02 metres/year).

A similar pattern is observed for the West Prairie River, in which water levels declined some 5.1 metres between 1970 and 1979 (0.56 metres/year). The West Prairie gauge was relocated in 1980 to a location near a grade control structure. The estimated water level for the mean discharge has varied by less than 0.01 metres over the 18-year period of record since the gauge was last moved. It is very likely that the apparent bed stability at the West Prairie River gauge is due to the local bed stabilizing effects of the grade control structure. The stability at the gauge does not necessarily reflect on the stability of the channel upstream of the railway bridge, where the bed is not stabilized.

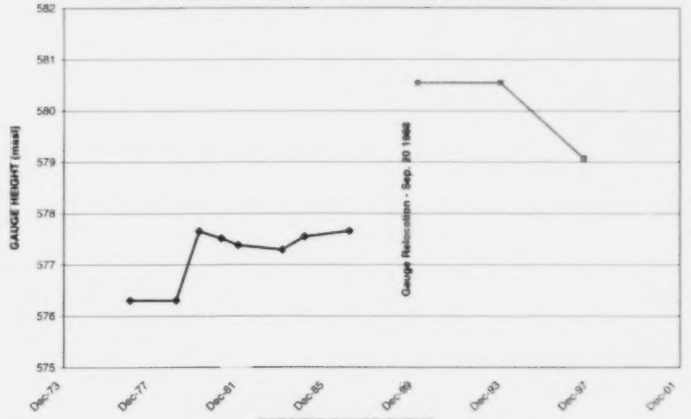
The Swan River at Kinuso gauge has been relocated several times over the period of record. Since the most recent relocation in 1977, water levels for the mean annual discharge have declined by 1.05 metres (0.04 metres/year over 24 years). The Swan River at Swan Hills gauge was also relocated several times over the life of the gauge. Since the most recent gauge relocation in 1983, water levels for the mean annual discharge have declined by 0.69 metres over a period of 18 years (0.04 metres/year).

The Driftpile River gauge shows only a 0.1 metre change in water levels for the mean annual discharge over the 5-year period spanned by the available rating curves, or an average annual rate of 0.02 metres/year.

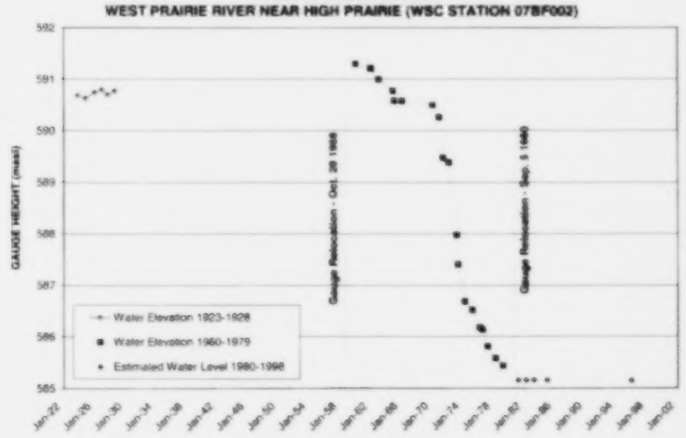
SPECIFIC GAUGE CURVE
LESSER SLAVE RIVER AT LESSER SLAVE LAKE



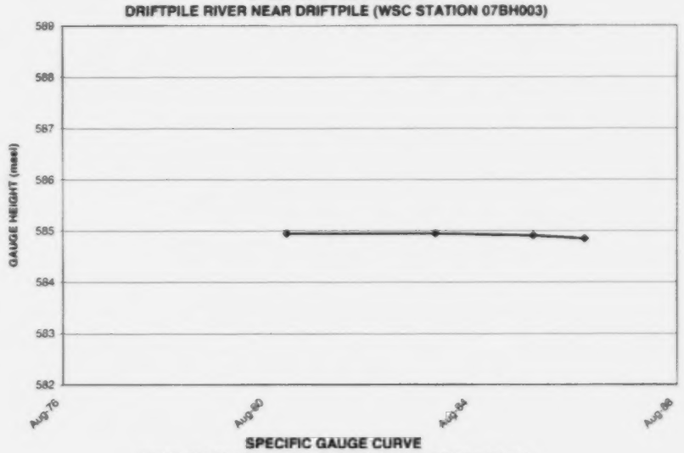
SPECIFIC GAUGE CURVE
SAWRIDGE CREEK NEAR LESSER SLAVE LAKE (WSC STATION 07BK009)



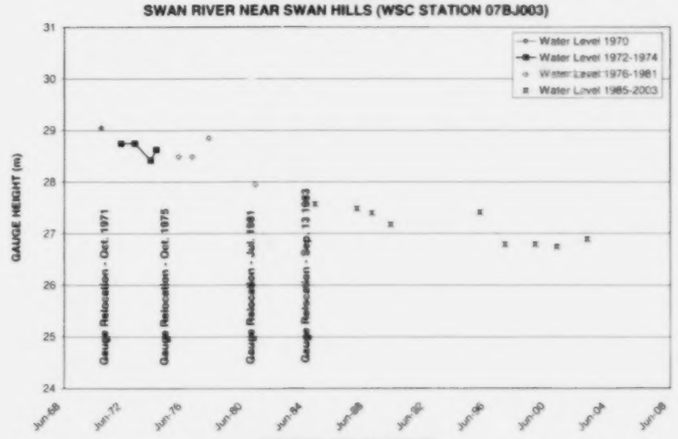
SPECIFIC GAUGE CURVE
WEST PRAIRIE RIVER NEAR HIGH PRAIRIE (WSC STATION 07BF002)



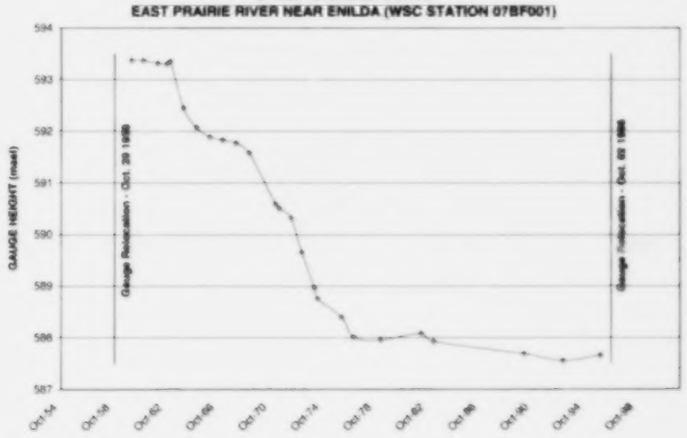
SPECIFIC GAUGE CURVE
DRIFTPILE RIVER NEAR DRIFTPILE (WSC STATION 07BH003)



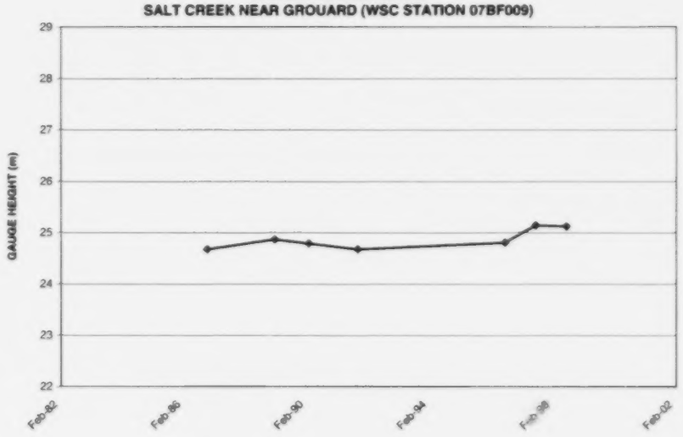
SPECIFIC GAUGE CURVE
SWAN RIVER NEAR SWAN HILLS (WSC STATION 07BJ003)



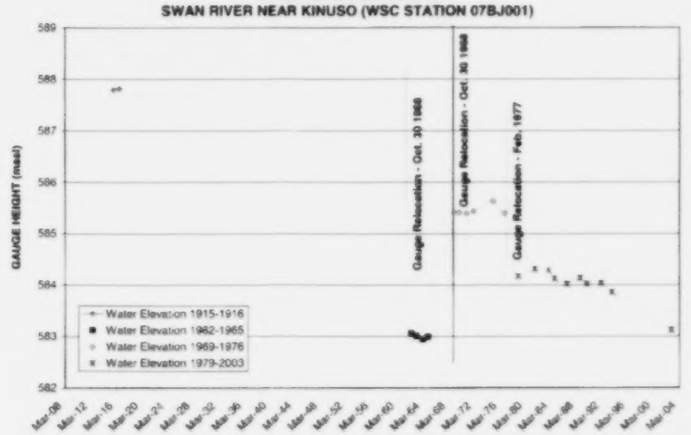
SPECIFIC GAUGE CURVE
EAST PRAIRIE RIVER NEAR ENILDA (WSC STATION 07BF001)



SPECIFIC GAUGE CURVE
SALT CREEK NEAR GROUARD (WSC STATION 07BF009)



SPECIFIC GAUGE CURVE
SWAN RIVER NEAR KINUSO (WSC STATION 07BJ001)



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CLIENT: ALBERTA ENVIRONMENT

PROJECT: LESSER SLAVE LAKE SEDIMENT STUDY

TITLE: SPECIFIC GAUGE CURVES

DATE	JOB No.	CAD FILE	FIGURE No.	REV.
MARCH 2005	CW1902	1902-S00.dwg	FIGURE 4	A

Comparison of the specific gauge curve results indicates that, after a prolonged period of relatively rapid declination in water levels for the average annual flow, the East Prairie and West Prairie channels have stabilized at the streamflow gauging locations, having achieved "stable" water level declination rates of 0.02 metres/year or less after a prolonged period of relatively rapid declination. These results are comparable to the observed declination rate in the Driftpile River. Both locations on the Swan River show slightly higher rates of declination than the other channels. Overall, the declination rates in the Swan River also appear to be relatively stable.

3.2.2 Comparative Surveys

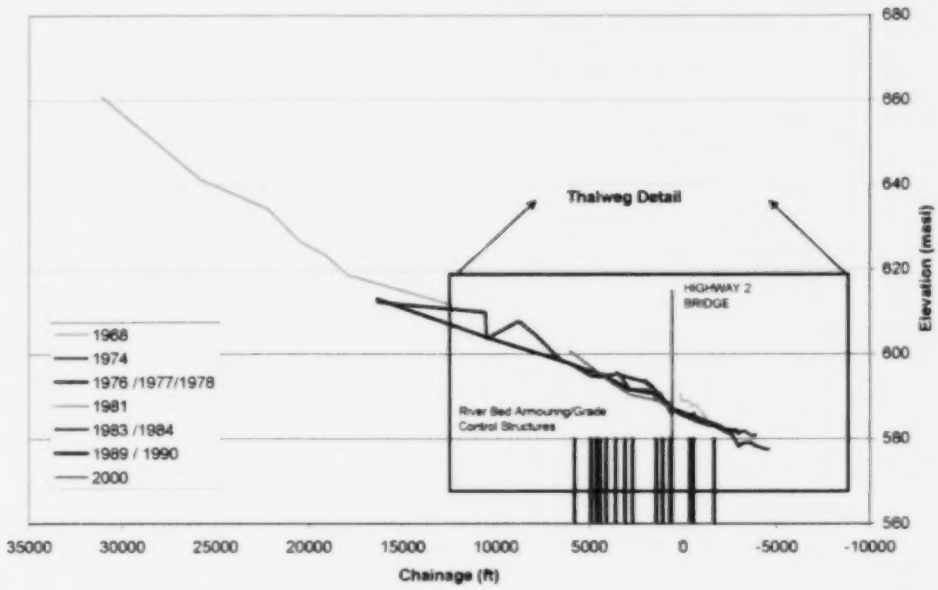
Alberta Environment has established cross-section locations along the East Prairie, West Prairie and South Heart River channels. Cross-sectional data are also available for the Swan River. Survey data provided by AENV for this study is summarized in Table 4; where possible and/or necessary these data were augmented with data scaled from hard copies of cross-sections presented in previous study reports.

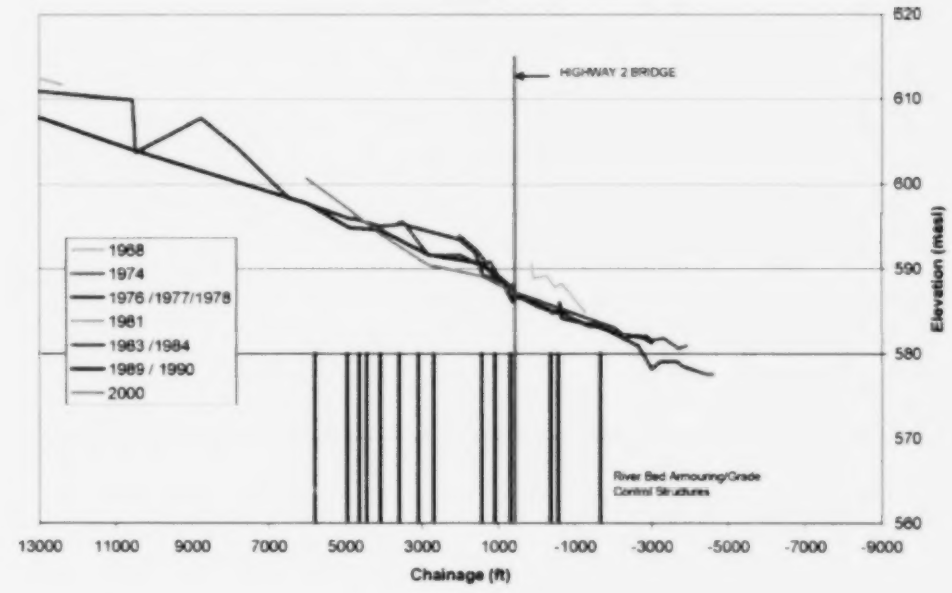
TABLE 4
Summary of Survey Data Available for Present Study

Channel	Survey Dates
East Prairie	1968, 1972, 1974, 1976/1977/1978, 1981, 1983/1984, 1989/1990, 2000
West Prairie	1972, 1974, 1975, 1976/1977, 1982/1983/1984, 1987, 1991/1992
South Heart	1979, 1982/1983/1984, 1991/1992
Swan	1978–1981, 1992, 2004
Driftpile	None

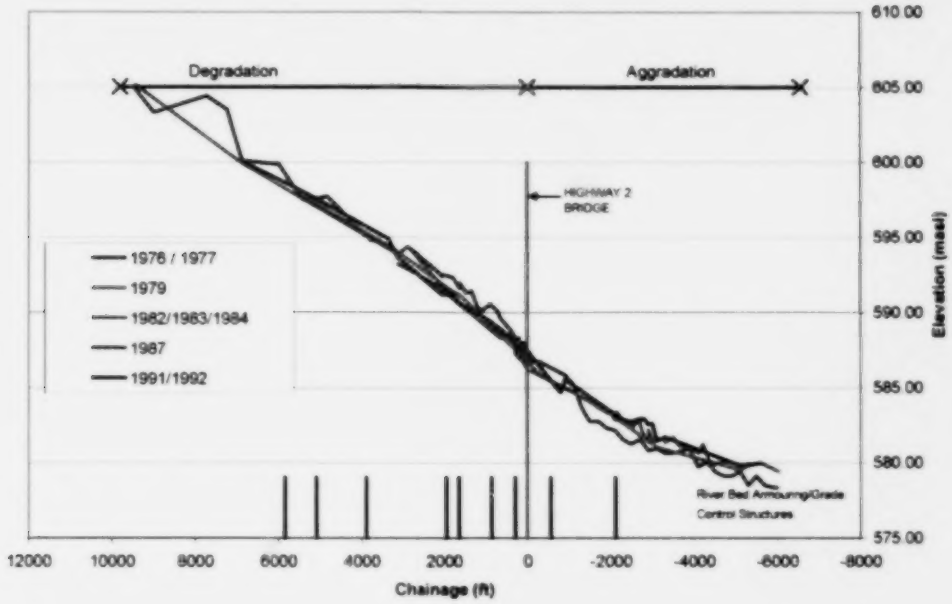
Thalweg profiles were generated for the East Prairie, West Prairie/South Heart and Swan Rivers using the survey data provided by Alberta Environment and additional thalweg elevation data obtained from scaling hard copies of published profiles. The profiles are presented in Figure 5.

The survey data sets are not available for all sections and all survey dates. Hence, definitive conclusions are difficult to draw on the basis of the thalweg profiles. For instance, the East Prairie River profile from 2000 indicates degradation in the area of the riverbed armouring/grade control structures placed in the 1990's, despite anecdotal evidence to the contrary that the bed armouring has effectively prevented further degradation in these areas (personal communication, Mr. Rod Burr, P.Eng., AENV). The West Prairie River profile is believed to provide a better representation of that channel, clearly indicating aggradation of the channel downstream of the Highway 2 bridge and bed degradation upstream of the Highway 2 bridge (there is a grade control weir downstream of the Highway 2 crossing). However, the most recent survey available for the West Prairie/South Heart River channel dates from 1991/1992 and may not represent the present (2005) state of the channel. Comparative survey data for the Swan River were not used to generate a thalweg profile along the entire extent of surveyed channel, as the cross-sections indicated a strong likelihood of a horizontal and vertical shift in the survey datums between the 1978–1981 and 1992 surveys.

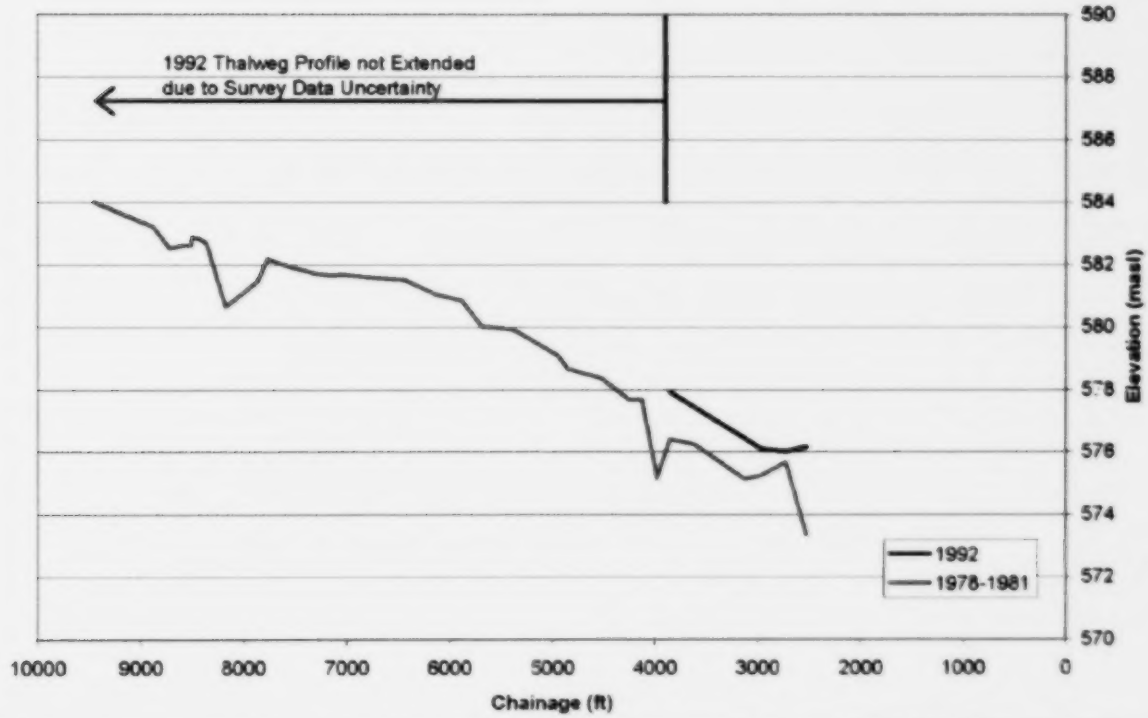

East Prairie River Thalweg Profiles
Thalweg Detail
HIGHWAY 2
BRIDGE
River Bed Armouring/Grade
Control Structures
1968
1974
1976 /1977/1978
1981
1983 /1984
1989 / 1990
2000
680
660
640
620
600
580
560
Elevation (masl)
35000
30000
25000
20000
15000
10000
5000
0
-5000
-10000
Chainage (ft)


East Prairie River Thalweg Profiles
Detail
HIGHWAY 2 BRIDGE
River Bed Armouring/Grade
Control Structures
1968
1974
1976 /1977/1978
1981
1983 /1984
1989 / 1990
2000
620
610
600
590
580
570
560
Elevation (masl)
13000
11000
9000
7000
5000
3000
1000
-1000
-3000
-5000
-7000
-9000
Chainage (ft)

West Prairie and South Heart River Thalweg Profiles



Swan River Thalweg Profiles



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CLIENT: ALBERTA ENVIRONMENT

PROJECT: LESSER SLAVE LAKE SEDIMENT STUDY

TITLE: RIVER THALWEG PROFILES

DATE	JOB No.	CAD FILE	FIGURE No.	REV.
MARCH 2005	CW1902	1902-S00.dwg	FIGURE 5	A

Digital channel cross-sectional data were provided by Alberta Environment. Surveyed channel sections were superimposed on one another, and channel areas below bankfull elevation were computed for the different survey dates. During this assessment, it was found that the Swan River sections surveyed in 2004 were consistently higher in elevation and displaced laterally from the previous survey, conducted between 1978 and 1981. It is unknown whether there has been a shift in the Swan River survey datum that could account for this apparent vertical and horizontal translation of the sections.

By comparing channel areas computed for different survey dates, it was possible to develop a sense of whether the channels were increasing or decreasing in cross-sectional area, which would indicate bed degradation or aggradation, respectively. This assessment was conducted for the East Prairie, West Prairie, South Heart and Swan Rivers.

The East Prairie River had survey data available for as recently as 2000, but only for sections upstream of the Highway 2 bridge. It was found that channel areas between the Highway 2 bridge and approximately 450 metres upstream (between Sections 408+42 U/S and 490+26 U/S) are increasing in area, indicating both bank erosion and bed degradation. Some of the cross-sections are widening, and bed levels at all of the sections in this reach of the river are lowering. Downstream of the Highway 2 bridge, comparative cross-sections were available only for the surveys dated 1984 and 1989, and at only two locations. This does not provide sufficient information and hence no conclusions can be drawn on the basis of the available survey data regarding any recent changes in the downstream reaches of East Prairie River.

The most recent available survey data made available for the West Prairie River date from 1991–1992. At that time, cross-sections upstream of Highway 2 were generally increasing in area due to both widening and downcutting. Downstream of Highway 2 and the grade control weir just downstream of the crossing, channel sections were generally decreasing in area, primarily as a result of aggradation and sediment deposition. No conclusions can be drawn on the basis of the available survey data regarding any recent channel changes along West Prairie River.

The most recent surveyed channel cross-sections for the South Heart River date from 1991. Comparing the 1991 sections to earlier surveys from the 1979 to 1983 period indicate that the channel was aggrading; as much as a metre of deposition along the bed is evident on the 1991 survey. This finding has been reported in numerous previous studies. Additional current survey data would be required to draw additional conclusions regarding sedimentation process in the South Heart River channel.

Survey data from 2004 were made available for the Swan River channel. Unfortunately, as noted earlier, there are strong indications from the comparative channel cross-section plots that the 2004 datum has been shifted from the 1978–1981 datum. The 2004 sections were adjusted to fit to the previous sections by matching top-of-bank points. The necessary vertical translations were inconsistent, ranging from 0 to 5 metres. Hence, no meaningful conclusions can be drawn by a comparison between the 1978-1981 and 2004 surveys. However, if the translations are

assumed to be valid, the cross-sections indicate localized areas of the channel bed lowering from 1.5 to 4 metres at Sections 8 and 19 and along the reach between Sections 13 and 16. There also appears to be a trend towards channel widening at most of the sections, with most sections showing an increase in channel width of 5 to 10 metres based on the 2004 survey.

Surveys apparently were completed of the delta areas entering Lesser Slave Lake. The original data sets are believed to have been collected by the Federal Government and have not been located. If the original data sets can be located and resurveyed, a much clearer understanding of the volume and rate of sediment deposition in these areas could be attained. In addition, Alberta Environment established several transects across Buffalo Bay in 1980 (e-mail communication, Mr. Jim Choles, P.Eng., Alberta Environment); the transects are understood to have been resurveyed in 1984. If these transects were re-established and periodically surveyed, then the amount and rate of sediment deposition in Buffalo Bay could be determined.

3.2.3 Sediment Generated by Bed Degradation and Bank Erosion

For the present study, there are insufficient recent data available to quantify up-to-date volumes of material eroded by or deposited within the subject channels, or to estimate the relative proportions of material being yielded by bank erosion versus bed degradation. However, this matter was examined in earlier studies, the results of which are summarized below.

Hardy (1989) examined the impacts of channelization in the East Prairie, West Prairie and South Heart Rivers on sedimentation in and downstream of the channels. They estimated that up to one-half of the sediment load in these three channels is generated within degrading channel reaches. This agrees with Outhet (AENV, 1977), who estimated that approximately 49% of all the sediment entering the Horse Lake/Buffalo Bay complex could be attributed to the impacts of upstream channel modifications, i.e. bed degradation and bank erosion induced by channel straightening.

Hydrocon (1984) assessed sediment and debris generation and transport in the East and West Prairie Rivers. They observed that, under natural conditions, the upper reaches of the East Prairie and West Prairie Rivers were the primary sources of sediment and debris in the channels and that the channels would have conveyed high sediment and debris loads. This is understood to be true based on the geomorphology of the channels.

The channels draining into the Lesser Slave Lake are no longer in a natural state. Development within the watersheds (discussed in Section 6.0) as well as numerous channel modifications have significantly altered the sediment and debris generation and transportation processes in these channels. A study conducted by NHCL at the same time as the Hydrocon study (NHCL, 1984) noted that the primary factor influencing sediment loads in the East Prairie and West Prairie Rivers was the impact of man-made works (specifically, channelization). NHCL estimated a sediment yield of 370,000 tonnes per year in the East Prairie River upstream of Highway 2 resulting from bed degradation and enhanced bank erosion upstream of the highway, attributing approximately 35% of the total to degradation and 65% of the total to bank erosion. Similarly for

the West Prairie River, an annual load of 158,000 tonnes was estimated for the total contribution of bed degradation and bank erosion, with the same proportions (35% bed/65% banks) as for the East Prairie River.

4.0 SEDIMENT LOADS

4.1 Available Data

Suspended sediment data are available for 19 sites in the Lesser Slave Lake watershed, including 8 sites operated by the Water Survey of Canada and 11 operated by Alberta Environment. The locations of the sediment monitoring stations are shown in Figure 1. The stations and periods of record are summarized in Table 5.

TABLE 5
Sediment Monitoring Stations in the Lesser Slave Lake Watershed

Station Identifier	Station Name	Operating Agency	Sampling Program
07BF001	East Prairie River near Enilda	WSC	1974–1983 Partial
07BF002	West Prairie River near High Prairie	WSC	1974–1983 Partial
07BH003	Driftpile River near Driftpile	WSC	1977 Partial 1978–1986 Full
07BJ001	Swan River near Kinuso	WSC	1969–1975, 1979-1988 Full
		AENV	1989, 1991, 1994, 1996 Partial
07BJ006	Lesser Slave Lake at Slave Lake	WSC	1980 Partial (1 measurement)
07BK001	Lesser Slave River at Slave Lake	WSC	1978, 1981 Partial
		AENV	1990-1997 Partial
07BK006	Lesser Slave River at Highway No. 2A	WSC	1977, 1979, 1980, 1982, 1988 Partial 1981, 1983 - 1987 Full
07BK009	Sawridge Creek near Slave Lake	WSC	1978 Partial
1	East Prairie River near Enilda	AENV	1974-1983, 1993-1994, 1996 Miscellaneous
2	West Prairie River near High Prairie	AENV	1974-1989, 1994, 1996, 1997 Miscellaneous
3	West Prairie River – Upstream	AENV	1976-1977, 1979 Miscellaneous
4	Iroquois Creek at Highway 2	AENV	1976-1977, 1983 Miscellaneous
5	Mud Creek	AENV	Unknown
6	Salt Creek at S.R. 750	AENV	1976 Miscellaneous
7	South Heart River Downstream of West Prairie River	AENV	1974, 1979, 1983 Miscellaneous
8	South Heart River Downstream of East Prairie River	AENV	1974, 1979, 1983 Miscellaneous
9	South Heart River at Upstream of West Prairie River	AENV	1977, 1979 Miscellaneous
10	South Heart River at Grouard Causeway	AENV	1976, 1983 Miscellaneous
11	East Prairie River near Metis Colony	AENV	1976–1977, 1979 Miscellaneous

Full sediment records (continuous daily sediment concentrations) are available for only three sites: Driftpile River, Swan River and Lesser Slave River downstream of Lesser Slave Lake. Records for all other stations comprise miscellaneous sediment measurements obtained via occasional sampling. Only a single site, Swan River, has year-round data (January to December). Most sediment monitoring in the Lesser Slave Lake watershed ceased in 1983, with some monitoring – primarily miscellaneous measurements – undertaken in the Swan, Driftpile, East Prairie and West Prairie Rivers between 1983 and 1997. Based on published records from WSC and data provided by AENV, no sediment data have been gathered in the past 7 years.

4.2 Annual Total Sediment Loads

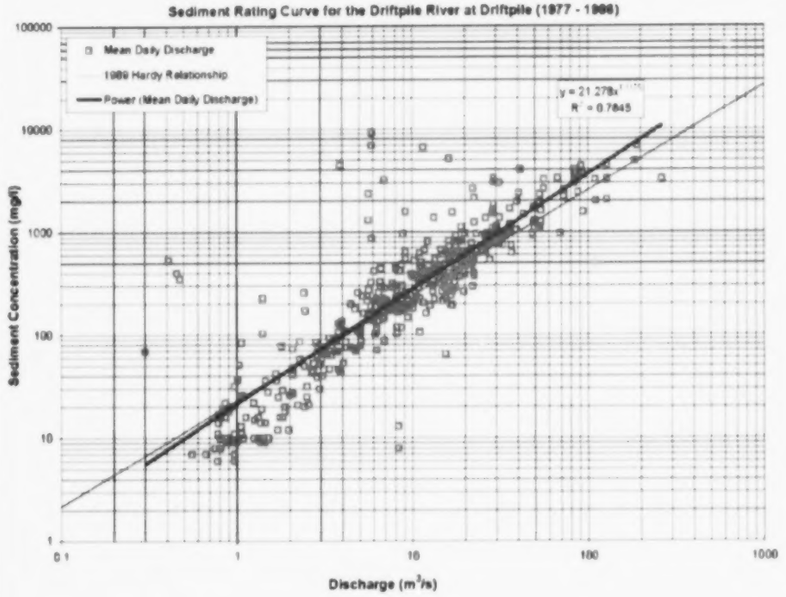
Annual suspended sediment loads were computed for the main channels flowing into the Buffalo Bay/Lesser Slave Lake system that had both suspended sediment and historical stream discharge data, i.e. West Prairie and East Prairie, Swan and Driftpile Rivers. Sediment rating curves provided by Alberta Environment were updated to include additional miscellaneous sediment measurements to 1997. The rating curves were adjusted using a bias correction factor which corrects for the underestimation introduced by a non-normal distribution of points about a fitted curve. The corrected sediment rating curves were applied to the historical streamflow record to estimate the range of annual total suspended sediment loads.

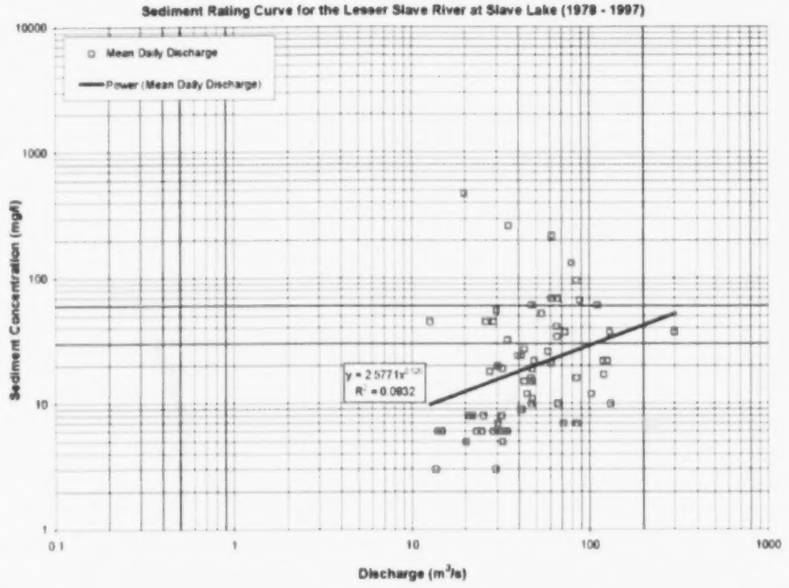
4.2.1 Sediment Rating Curves

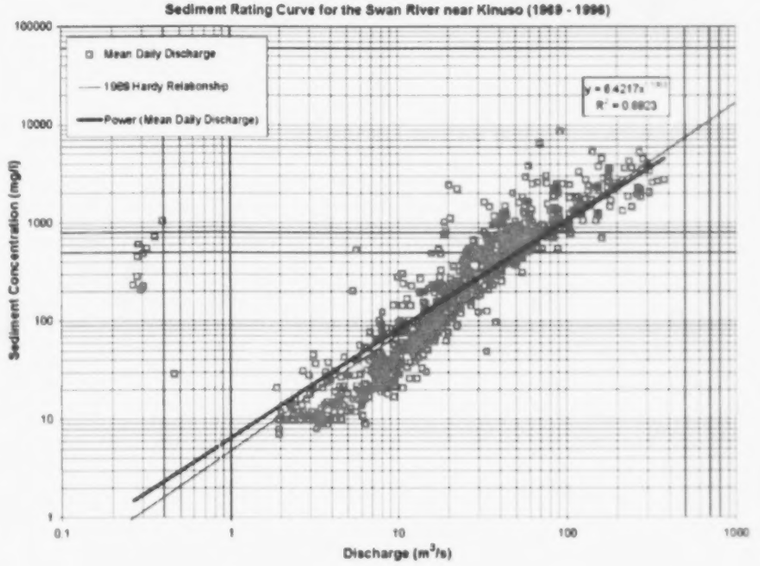
Sediment rating curves were produced in the Hardy (1989) study, using the data available to 1986. The sediment rating curves were updated for this study using the additional data gathered between 1986 and 1997. The updated sediment rating curves are presented in Figure 6.

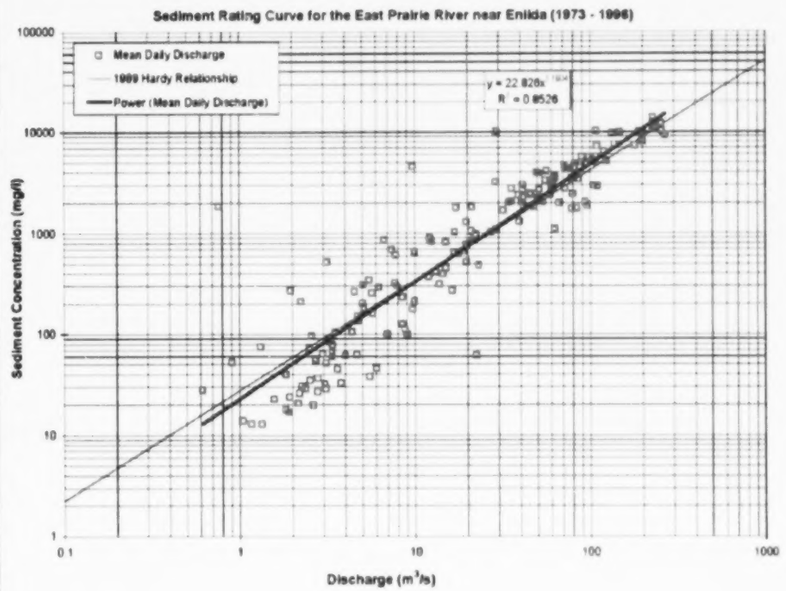
The additional data had little impact on the sediment rating curves for the West Prairie River and Lesser Slave River at Highway 2A sites, whereas the rating curves for East Prairie River and Driftpile River have steepened slightly, indicating an increase in sediment loading at higher flows and a decrease in sediment loading at lower flows. The rating curve for Swan River has decreased in slope, indicating higher sediment outputs at lower flows and lower sediment outputs for higher flows. High (0.73 to 0.85) R^2 values were obtained for the sediment-discharge correlations for the Swan, Driftpile, East Prairie and West Prairie Rivers. The R^2 values determined for the two Lesser Slave River sites were much lower (0.09 and 0.46).

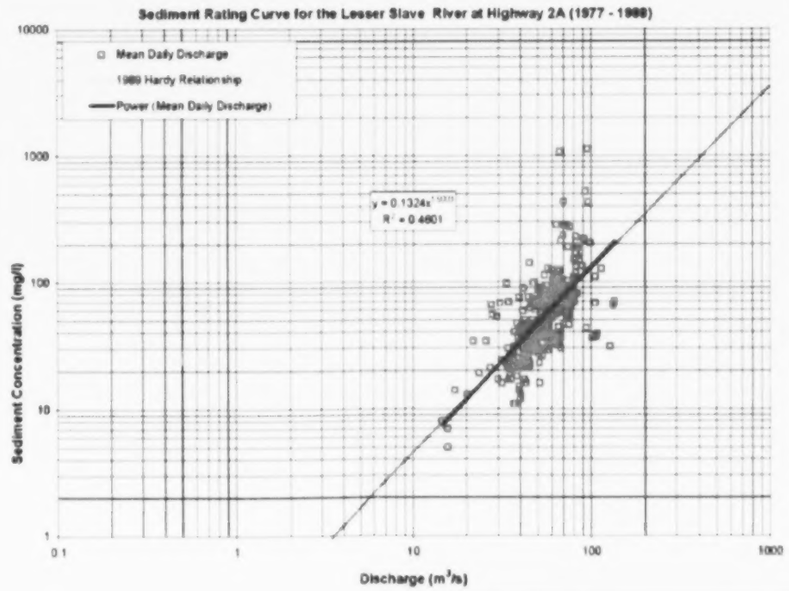
Bias correction factors were computed for, and applied to, the sediment rating curves to provide more realistic estimates of sediment concentrations as a function of discharge (see detailed discussion in Appendix A).

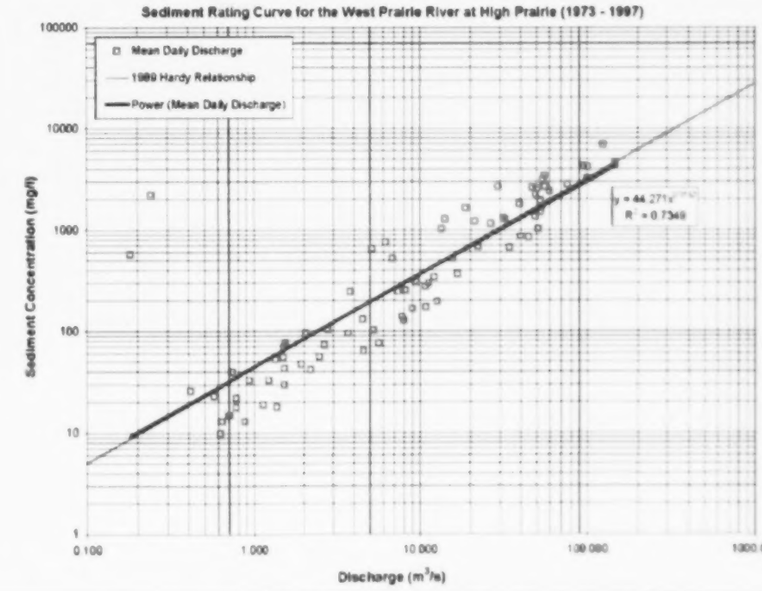

Sediment Rating Curve for the Driftpile River at Driftpile (1977 - 1998)
Mean Daily Discharge
1989 Hardy Relationship
Power (Mean Daily Discharge)
y = 21.278x^1.1
R² = 0.7845
Sediment Concentration (mg/l)
Discharge (m³/s)


Sediment Rating Curve for the Lesser Slave River at Slave Lake (1978 - 1997)
Mean Daily Discharge
Power (Mean Daily Discharge)
y = 2.5771x^0.5
R² = 0.0832
Sediment Concentration (mg/l)
Discharge (m³/s)


Sediment Rating Curve for the Swan River near Kinuso (1989 - 1996)
Mean Daily Discharge
1989 Hardy Relationship
Power (Mean Daily Discharge)
y = 8.4217x^1.3
R² = 0.8823
Sediment Concentration (mg/l)
Discharge (m³/s)


Sediment Rating Curve for the East Prairie River near Enilda (1973 - 1996)
Mean Daily Discharge
1989 Hardy Relationship
Power (Mean Daily Discharge)
y = 22.826x^1.1
R² = 0.8526
Sediment Concentration (mg/l)
Discharge (m³/s)


Sediment Rating Curve for the Lesser Slave River at Highway 2A (1977 - 1998)
Mean Daily Discharge
1989 Hardy Relationship
Power (Mean Daily Discharge)
y = 0.1324x^1.9
R² = 0.4601
Sediment Concentration (mg/l)
Discharge (m³/s)


Sediment Rating Curve for the West Prairie River at High Prairie (1973 - 1997)
Mean Daily Discharge
1989 Hardy Relationship
Power (Mean Daily Discharge)
y = 44.271x^1.2
R² = 0.7349
Sediment Concentration (mg/l)
Discharge (m³/s)

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PROJECT: LESSER SLAVE LAKE SEDIMENT STUDY

TITLE: SEDIMENT RATING CURVES

DATE	JOB No.	CAD FILE	FIGURE No.	REV.
MARCH 2005	CW1902	1902-S00.dwg	FIGURE 6	A

4.2.2 Sediment Loads

Annual total suspended sediment loads were computed for the East Prairie, West Prairie, Swan and Driftpile Rivers using recorded daily mean streamflow data and the corrected sediment rating curves. The results are presented in Figure 7 and summarized in Table 6.

TABLE 6
Annual Total Suspended Sediment Loads

Channel	Seasonal or Annual[1] Total Suspended Sediment Load (tonnes/year)		
	Minimum	Mean	Maximum
East Prairie River	20,200	847,000	6,950,000
West Prairie River	5,870	284,000	1,930,000
Swan River	28,600	538,000	2,800,000
Driftpile River	12,500	337,000	960,000

1. Only West Prairie River and Swan River have sufficient data to compute annual sediment loads. Seasonal loads are presented for the remaining locations.

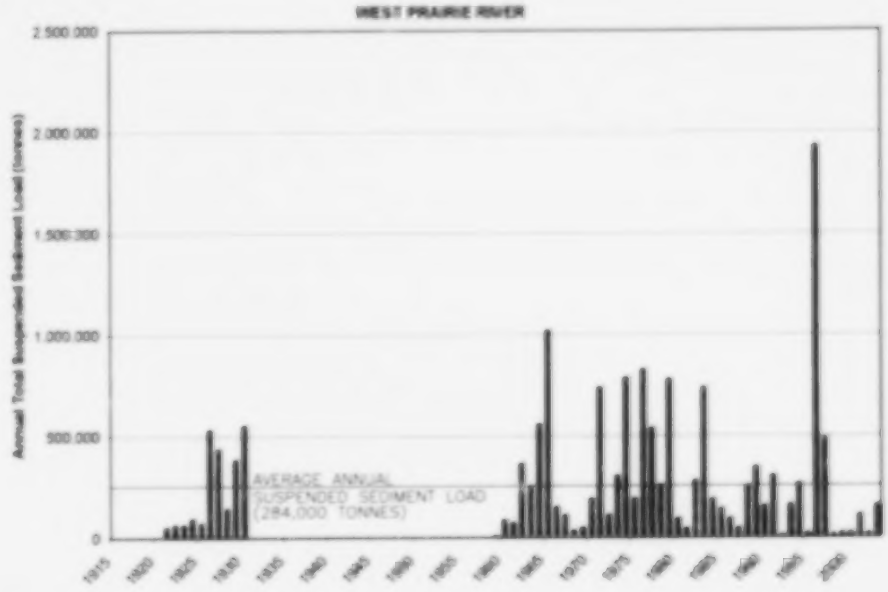
Of the stations listed in Table 6, only the West Prairie River and Swan River have year-round records of streamflow; streamflow records for the Driftpile and East Prairie Rivers are seasonal (March to October) only. Annual total sediment loads were computed for the Swan River and West Prairie River on the basis of both the full year (January to December) and seasonal (March to October) periods of record. For both channels, the annual total computed on the basis of a complete year of record (January to December) was less than 0.1% greater than the annual total computed on the basis of seasonal (March to October) data. Hence, the assumption can be made that annual total suspended sediment loads computed on the basis of seasonal discharge data are a reasonable estimation of the true annual suspended sediment loads in these channels.

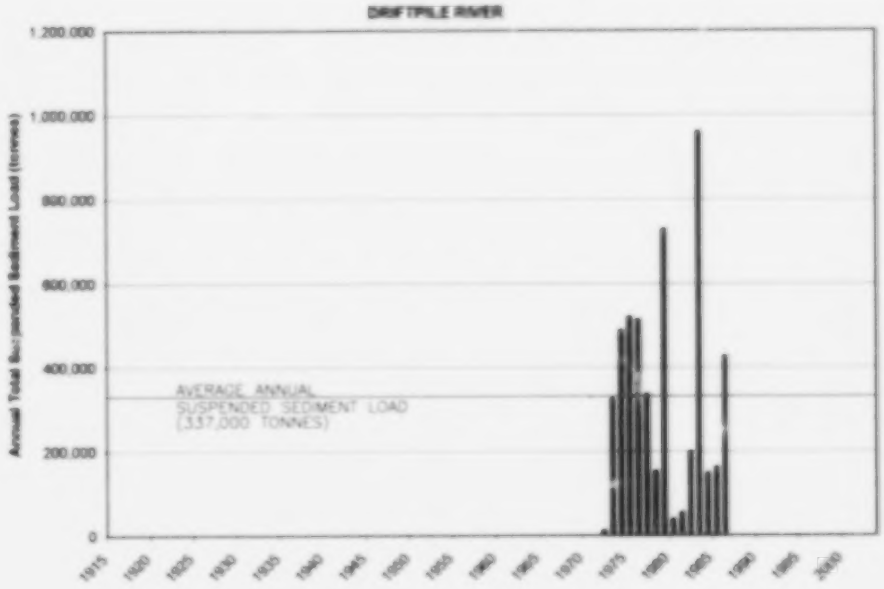
Annual sediment loads published by Water Survey of Canada (Environment Canada, 2002) as well as values published in previous studies are presented in Table 7.

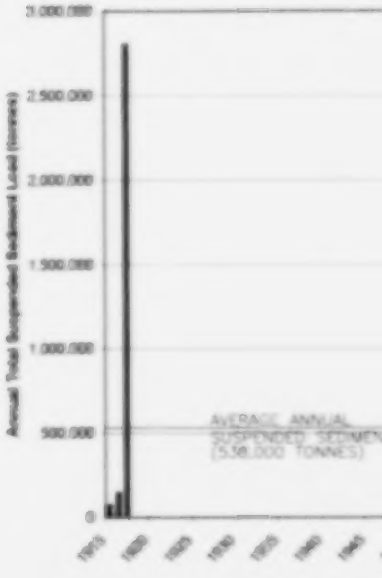
TABLE 7
Comparison of Annual Suspended Sediment Loads with Previous Estimates

Channel	Average Annual Suspended Sediment Load (tonnes)				
	Water Survey of Canada (1988)	Alberta Environment (Outhet, 1977)	NHCL (1984)	Hardy (1989)	AMEC (2005)
East Prairie	N/A	461,000	861,000	1,009,000	847,000
West Prairie	N/A	93,500	391,000	371,000	284,000
Swan	396,000	N/A	N/A	494,000	538,000
Driftpile	179,000	N/A	N/A	252,000	337,000

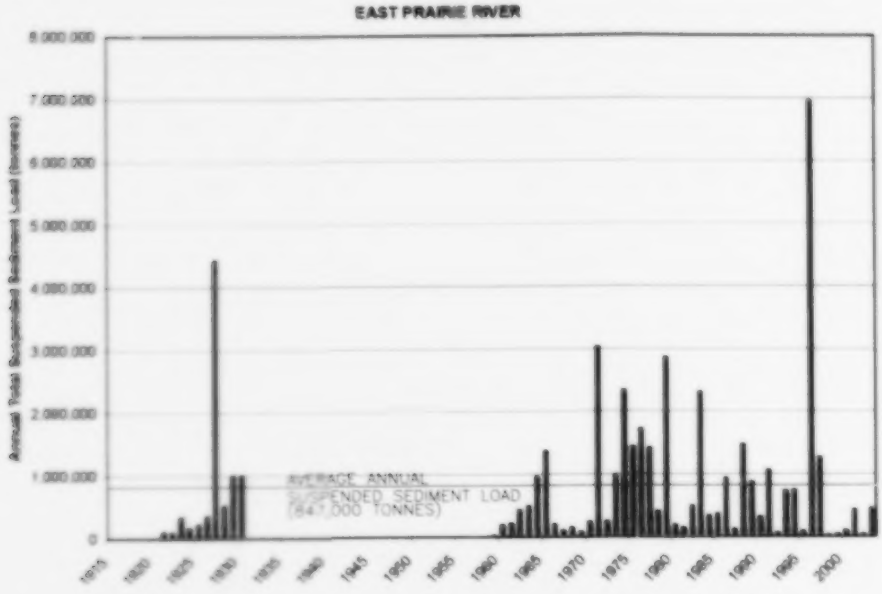
N/A = Not Available

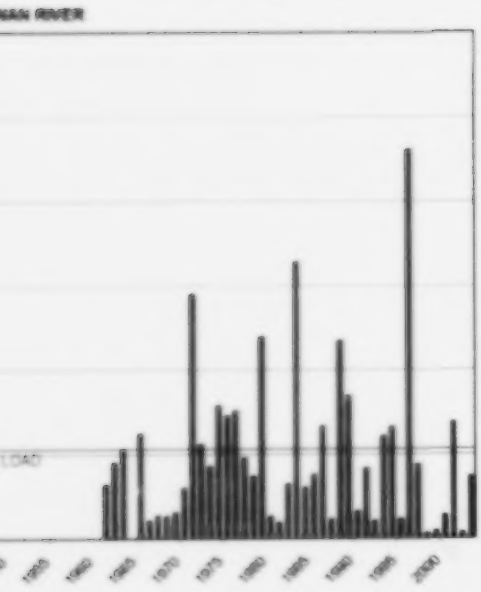


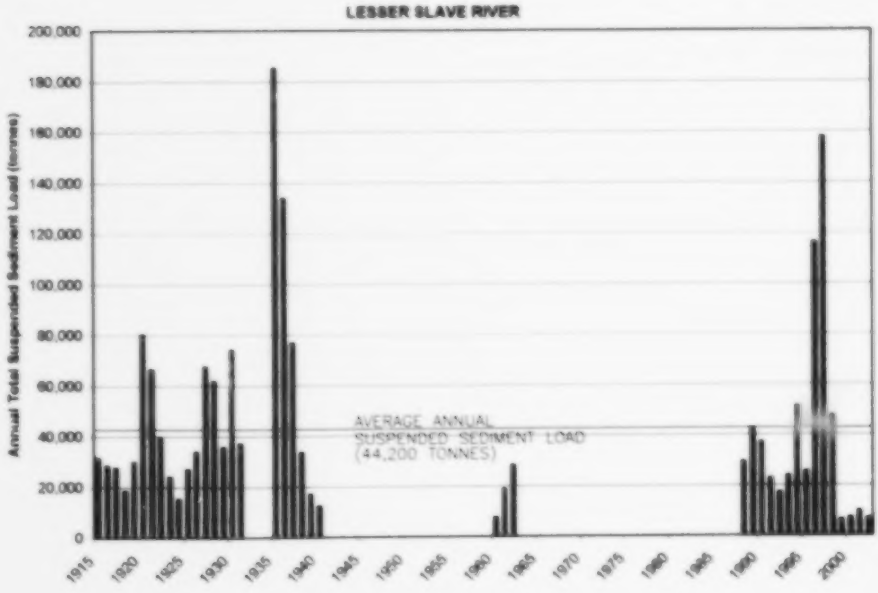




NOTE:
SEDIMENT LOADS SHOWN HAVE BEEN COMPUTED ON THE BASIS OF RECORDED STREAMFLOW DATE AND THE SEDIMENT RATING CURVES FOR THE CHANNELS (SHOWN ON FIGURE 6).







amec Earth & Environmental

CLIENT: ALBERTA ENVIRONMENT

PROJECT: LESSER SLAVE LAKE SEDIMENT STUDY

TITLE: ANNUAL TOTAL SUSPENDED SEDIMENT LOAD

DATE	JOB No.	CAD FILE	FIGURE No.	REV.
MARCH 2005	CW1902	1902-S00.dwg	FIGURE 7	A

The total sediment load in the river is comprised of two components: the suspended sediment load and the bed load. Several authors have discussed the respective proportions of suspended sediment to bed load in the Lesser Slave Lake Basin. Yaremko (NHCL, 1984) determined that 6% of the total sediment load in the East Prairie River channel is transported as bed load. Outhet (AENV, 1977) estimated that bed load represents 10% of the total sediment load. For this study, Outhet's estimate of bed load as 10% of the total sediment load has been adopted. Computed average total (suspended + bed) sediment loads are summarized in Table 8.

TABLE 8
Average Annual Total Sediment Loads

Channel	Average Annual Total Sediment Loads (tonnes)		
	Suspended	Bed	Total
East Prairie	847,000	94,000	941,000
West Prairie	284,000	32,000	316,000
Swan	538,000	60,000	598,000
Driftpile	337,000	37,000	374,000

4.3 Lesser Slave Lake Sediment Budget

The average annual sediment balance for Lesser Slave Lake is summarized in Table 9. The sediment balance illustrates the source and disposition of sediment in the watershed, as discussed below.

Approximately 47% of the watershed, including East Prairie, South Heart and West Prairie Rivers and Salt Creek drain into the extreme west end of Lesser Slave Lake through Buffalo Bay and the Buffalo Bay outlet channel. Most of the sediment carried into the Horse Lakes/Buffalo Bay area settles out within the delta. Outhet (AENV, 1977) estimated that 85% of the sediment entering the area settles out in the channels and marshes upstream of Buffalo Bay. Hardy (1989) estimated that proportion of sediment settling out upstream of Buffalo Bay to be 90% whereas Yaremko (NHCL, 1983) suggested that the amount of sediment entering Buffalo Bay may be greater than that estimated by Outhet but did not quantify the amount. Alberta Environment (1988) estimated that 10 to 20% of the West Prairie River sediment load is conveyed to Buffalo Bay and that, due to deposition in the Horse Lakes and associated marshy areas upstream, only a fraction of the total sediment load in the East Prairie and West Prairie Rivers is deposited in Buffalo Bay.

There is limited suspended sediment data at the Grouard causeway at the outlet of Buffalo Bay with which to test previously published estimates. However, three suspended sediment measurements were made at near the same time as suspended sediment measurements upstream in South Heart and East Prairie Rivers. For the three measured events, sediment concentrations at Grouard varied from 0.5 to 43% of the total upstream concentrations, with an average of 16%. Hence, Outhet's estimate of 85% settlement upstream of Buffalo Bay has been assumed for this study.

Average annual sediment yields from ungauged areas in the Lesser Slave Lake watershed vary. Estimates ranging from 10 to 100 tonnes/km^2 for agricultural land are quoted in Hardy (1989), who used a value of 50 tonnes/km^2 for ungauged basins. Outhet (AENV, 1977) estimated sediment yields of 56 tonnes/km^2 to 170 tonnes/km^2 for natural areas in the East Prairie and West Prairie River watersheds upstream of Highway 2, although measured sediment yields from Iroquois Creek, a natural area in the West Prairie River watershed, are in the order of 27 tonnes/km^2. For this study, the 50 tonnes/km^2 value quoted by Hardy has been adopted for ungauged areas as being a representative mid-range value. The sensitivity of the sediment balance to the adopted value for sediment yield from ungauged areas is discussed later in this section.

The computed average annual total suspended sediment load into the Horse Lakes/Buffalo Bay area from the East Prairie, South Heart and West Prairie River channels is 1,280,000 tonnes. This is based on computed suspended sediment loads in the East Prairie and West Prairie Rivers (847,000 tonnes and 284,000 tonnes, respectively) plus estimated suspended sediment loads for the South Heart River watershed upstream of the West Prairie River confluence and for the ungauged areas, including Salt Creek, draining to Buffalo Bay. An average annual suspended sediment load of 47 tonnes/km^2 has been estimated for the South Heart River watershed upstream of the West Prairie River confluence (per Hardy, 1989), to yield 139,000 tonnes. The sediment input from the ungauged portions of the Buffalo Bay drainage area, including Salt Creek, was computed at 23,000 tonnes using an estimated sediment yield of 50 tonnes/km^2 (Hardy, 1989).

It is assumed that sediment transported as bed load in the channels is deposited within the Horse Lakes/Buffalo Bay delta complex. Hence, the sediment loads summarized in Table 9 are suspended sediment loads and do not include the bed load of the respective channels.

TABLE 9
Lesser Slave Lake Sediment Budget

Lesser Slave Lake Tributary Watershed	Drainage Area (km^2)	Sediment Yield[1] (tonnes/km^2)	Computed Sediment Load[1] (tonnes)
Horse Lakes/Buffalo Bay Basin			
South Heart	2,950	47	139,000
West Prairie (upstream of South Heart)	1,410	201	284,000
East Prairie (at Mouth)	1,580	536	847,000
Ungauged Tributaries to Buffalo Bay	462	50	23,000
Subtotal Of Sediment Loads			1,290,000
Amount Deposited Upstream of and In Buffalo Bay (85%)			1,100,000
Sediment Outflow from Buffalo Bay at Grouard Causeway (15%)			190,000
Driftpile River (at Mouth)	860	392	337,000
Swan River (at Mouth)	2,230	241	538,000
Ungauged Tributaries	2,910	50	146,000
Sediment Outflow to Lesser Slave River at Slave Lake [2]			44,200
Net Deposition in Lesser Slave Lake (Sediment inflow from Grouard, Driftpile River, Swan River and ungauged tributaries less sediment outflow to Lesser Slave River)			1,170,000

(1) Based on suspended sediment loads. Values have been rounded to three significant figures.
(2) Based on bias-corrected mean annual suspended sediment load in Lesser Slave River at Slave Lake (WSC Station 07BK001) averaged over the period of record.

The computed total annual sediment deposition in Lesser Slave Lake and the Horse Lakes/ Buffalo Bay complex is 2,270,000 tonnes. This compares with the range of 2,230,000 to 2,250,000 tonnes computed by Hardy (1989).

As a check on the sedimentation calculations for the Lesser Slave Lake, the trap efficiency of the lake was calculated and used to estimate the potential range of sediment outputs from the lake. Trap efficiency curves developed by Brune (1953) provide a means of estimating the percent of sediment trapped as a function of the capacity-inflow ratio (i.e. storage volume in the lake as a ratio of the mean annual total inflow to the lake). The storage capacity of Lesser Slave Lake is 13,200,000 dam^3 (Mitchell and Prepas, 1990). The mean annual total inflow to Lesser Slave Lake was computed based on historical flow records for the East Prairie, West Prairie, Swan and Driftpile Rivers to be 2,415,300 dam^3 (1 dam^3 equals 1 000 m^3). The mean annual total discharge from ungauged areas in the Lesser Slave Basin (approximately 6,800 km^2) was prorated on a drainage basis using data from mean annual discharge data from Sawridge Creek. The capacity-inflow ratio for Lesser Slave Lake was computed to be 5.47. Using

Brune's trap efficiency curves, it is estimated that at least 97% of the inflowing sediment should settle in the lake. Based on the computed annual total sediment inflow from Buffalo Bay plus Swan River, Driftpile River and ungauged tributary sediment contributions, it is estimated that some 1,180,000 tonnes of sediment are deposited annually in Lesser Slave Lake. This matches closely with the sediment balance estimate of 1,170,000 tonnes/year. The equivalent volume of this annual sediment load is estimated to be approximately 1 257 000 m^3, or less than 0.01% of the total volume of Lesser Slave Lake. At the present rate of sedimentation, it would take more than 10,000 years to fill Lesser Slave Lake.

The greatest uncertainty in the Lesser Slave Lake sediment balance summarized in Table 9 is associated with the assumed sediment yield from the ungauged areas. Doubling the assumed sediment yield to 100 tonnes/km^2 increases the net annual sediment deposition in Lesser Slave Lake to 1,280,000 tonnes, or approximately 10% more than with the lower assumed sediment yield of 50 tonnes/km^2. With this increased rate of sedimentation, it would take approximately 9,500 years to fill Lesser Slave Lake.

5.0 SEDIMENT DEPOSITION

5.1 Historical Air Photo Interpretation

Historical air photos of selected major delta areas of Lesser Slave Lake were examined to assess the effects of progressive sedimentation and/or erosion. Specifically, the assessment was undertaken to determine whether depositional areas are increasing, decreasing or remaining stable in area, at what rate the delta areas are changing and whether specific sources of sediment could be related to the changes in delta area.

The areas assessed included the Driftpile River outlet and delta, the Buffalo Bay area with the combined delta of South Heart River, West Prairie River and Salt Creek, the Swan River outlet, and the mouth of the Lesser Slave River. Air photos spanning the period from 1949 to the 1990's as well as the most current available satellite imagery (2000 to 2003) were used in the analysis. The assessment took into account the effects of varying water levels on Lesser Slave Lake, which produce variations in the shoreline that are independent of sediment and erosion processes.

The river delta common to the South Heart River, West Prairie River and Salt Creek on the north shore of Buffalo Bay has shown significant growth due to sedimentation, as shown in Figure 8. Over the past 53 years, the delta has advanced approximately 500 metres into Buffalo Bay, with significant increases in overall delta area. High water levels at the time of the 1979 air photo give a false sense of delta recession, as only the relatively high naturally occurring dykes along the channel banks remained unsubmerged during that high water event.

The Swan River has developed a large delta at the mouth, although the location of the river outlet has significantly changed locations over the past 53 years. The original (1949) river mouth was located at the northern tip of the peninsula with a northeasterly direction of discharge. Following a channel cut-off that formed sometime between 1965 and 1983, the mouth moved to the northwest side of the delta, as shown in Figure 9. Portions of the original delta were rapidly

eroded and new delta areas were quickly developed by river sediment. Over the short time span from 1982 to 2003 (21 years), the new river delta has advanced approximately 400 metres into Lesser Slave Lake. Conversely, the old delta has retreated almost 200 metres. Some of the new delta formation may be attributed to littoral processes acting on the old delta.

The delta at the mouth of the Driftpile River also shows signs of sediment deposition and growth over time. As shown in Figure 10, the river delta has advanced into Lesser Slave Lake approximately 625 metres over the past 53 years.

The Lesser Slave River is the outflow channel of Lesser Slave Lake. At the lake outlet, there are few signs of either sediment deposition or erosion as shown in Figure 11. After taking the effects of varying water levels into account, the changes in shoreline position appear to be negligible. The extensive river training works associated with the bridge crossing immediately downstream of the outlet and the lake level control weir may account in part for the stability of the shoreline at this location.

5.2 Visible Areas of Sediment Deposition and Delta Growth

To determine the slopes of the river deltas, air photos taken in close sequence over subsequent years under different water level conditions were compared. In this analysis, the assumption is that the sediment deposition over the intervening period between the air photos is minimal due to the short time span between the respective air photos. The slope of the delta can then be computed as the horizontal difference in the position of the delta shoreline over the change in water level. To assess delta growth over time, air photos taken at times of similar water levels, but over a wide range of years, were compared.

The slope of the river delta common to the South Heart River, West Prairie River and Salt Creek on the north shore of Buffalo Bay was determined by comparing the 1981 and 1979 air photos. The water level of Lesser Slave Lake was 576.551 and 578.315 metres, respectively; on the dates the air photos were flown (difference in water level of 1.764 metres). The average distance between the shorelines on the two photos is approximately 320 metres. This results in a typical delta slope of 0.006 m/m. The growth of the Buffalo Bay delta area was assessed using air photos dating from 2003 and 1961. The water level of Lesser Slave Lake was 575.958 and 575.874 metres respectively at the time of the air photos (difference in water level of 0.084 m). Over the span of 42-year period spanned by the air photos, the delta grew an average of approximately 330 metres (7.9 metres/year). The maximum delta growth was 810 metres (19.3 metres/year), whereas in some areas zero delta growth occurred.

A similar method of analysis was followed for the remaining delta areas. The results are summarized in Table 10.

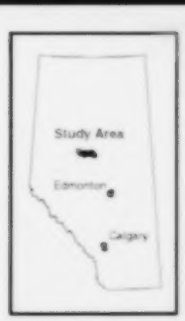
Legend

- 2003 Shoreline 575.958 (Slave Lake)
- 1982 Shoreline 576.261 (Faust)
- 1981 Shoreline 576.551 (Faust)
- 1961 Shoreline 575.874 (Faust)
- 1950 Shoreline (Water Level Unknown)

150 0 150 300

Meters

1:12,000



Alberta Environment

Lesser Slave Lake Sedimentation Study

Comparative Shoreline Analysis: Buffalo Bay Outlet

Figure 8

September 1982 Aerial Photograph

Legend

- 2003 Shoreline 575.900 (Slave Lake)
- 1999 Shoreline 575.958 (Slave Lake)
- 1983 Shoreline 576.770 (Faust)
- 1982 Shoreline 576.261 (Faust)
- 1965 Shoreline 578.065 (Faust)
- 1949 Shoreline (Photo Date/Water Level Unknown)

200 0 200 400

Meters

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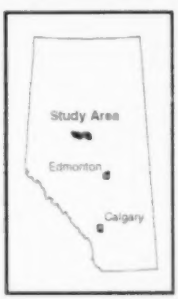


Alberta Environment

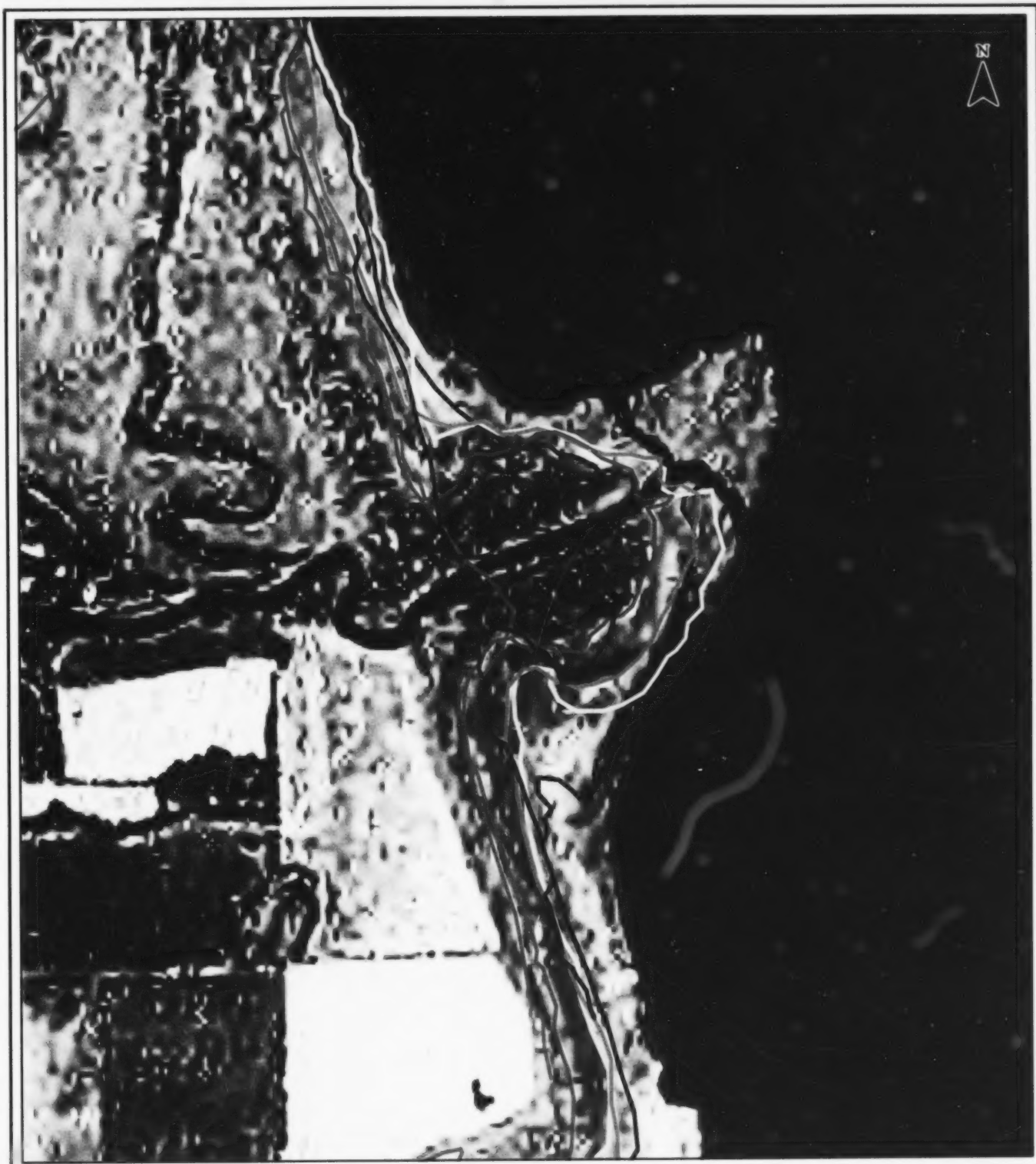
Lesser Slave Lake Sedimentation Study

Comparative Shoreline Analysis: Swan River Outlet

March, 2005	UTM Zone 11	NAD83
CW1902		
dwan		
dwan, 05-03-22		

Figure 9

August 1999 Aerial Photograph



Legend

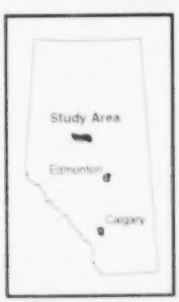
- 2003 Shoreline 575.944 (Slave Lake)
- 1990 Shoreline 576.732 (Faust)
- 1983 Shoreline 577.040 (Faust)
- 1981 Shoreline 576.541 (Faust)
- 1980 Shoreline 576.839 (Faust)
- 1966 Shoreline 577.121 (Faust)
- 1949 Shoreline 576.346 (Faust Approximate)

2003 IRS Mosaic

150 0 150 300

Meters

1:12,000



Alberta Environment

Lesser Slave Lake Sedimentation Study

Comparative Shoreline Analysis: Driftpile River Outlet

March 2005 | UTM Zone 11 | NAD83

CW1932

driftpile

driftpile 05-03-22

Figure 10

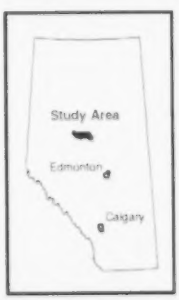
Legend

- 2003 Shoreline 576.003 (Slave Lake)
- 1987 Shoreline 576.482 (Faust)
- 1983 Shoreline 575.807 (Faust)
- 1981 Shoreline 576.541 (Faust)
- 1965 Shoreline 578.065 (Faust)
- 1949 Shoreline (Photo Date/Water Level Unknown)

150 0 150 300

Meters

1:12,000



Alberta Environment

Lesser Slave Lake Sedimentation Study

Comparative Shoreline Analysis: Lesser Slave River

March 2005	TM Zone 11	NAD83
CW1932		
outlet to br		
outlet to br 05-03-22		

Figure 11

June 1987 Aerial Photograph

TABLE 10
Delta Slopes and Rates of Growth

Delta Area	Air Photo Analysis Period[1]	Air Photo Analysis Period Sediment Flow-Through (tonnes)	Delta Slope (m/m)	Delta Growth Over Air Photo Analysis Period [1]		
				Minimum	Average	Maximum
West Prairie/ South Heart (Buffalo Bay)	1961 to 2003	13,200,000 plus sediment input from Salt Creek	0.006	Slight loss (recession)	330 metres (7.9 m/yr)	810 metres (19.3 m/yr)
East Prairie (Grouard Causeway)	1982 to 2000	18,300,000	0.021	Slight loss (recession)	100 metres (5.6 m/yr)	385 metres (21.4 m/yr)
Swan River	1982 to 1999	10,300,000	0.009	150 metre loss (8.8 m/yr)	400 metres (23.5 m/yr)	850 metres (50 m/yr)
Driftpile River	1949 to 1990	N/A Gaps in Discharge Data	0.011	Slight loss (recession)	150 metres (3.7 m/yr)	360 metres (8.8 m/yr)

[1] Air photos taken at similar lake water levels and selected to cover as long a period of time as possible.

It is difficult to correlate delta growth events to the deposition of sediment derived from specific sediment sources within the respective watersheds. This is due to:

- air photos are rarely taken at similar lake water levels. Hence, there is considerable difficulty in apportioning the change in delta area between sediment deposition and increased delta exposure due to a lower lake level. If the water level increases between air photo dates, an apparent shrinkage in delta area is observed, despite ongoing sediment deposition;
- air photo analyses do not account for loss of sediment from the delta areas due to littoral drift. For example, approximately 10% of the area of the Swan River delta was eroded at the northeast corner of the delta after the river mouth switched location from the northeast corner to the northwest side of the delta, as shown in Figure 9; and
- there is an indeterminate time lag between when the sediment-producing activities in the watersheds occur and when the effects are seen at the deltas.

5.3 Littoral Transport

Sediment can be transported along a shoreline by the process of littoral transport, or littoral drift. As waves wash up on the shoreline at an angle, they create a current parallel to the shoreline called the longshore current. This current can move sediment along the shoreline. In the Lesser Slave Lake, the prevailing winds are from the west/northwest. Wind-induced waves striking the south shoreline of Lesser Slave Lake will therefore typically create an easterly longshore current, which will transport sediment from the west end of the lake towards the mouth at the southeast end of the lake. Littoral transport contributes to the transport of sediment towards the mouth and out of the lake via the Lesser Slave River, and thus may play a

role in the operation of water management structures in the river downstream of the lake. However, littoral transport is not a significant factor in the generation of sediment in the watershed or the transport of that sediment to the respective river deltas, as evidenced by the computed annual littoral sediment transport load (44,200 tonnes) presented in Table 9 as sediment outflow to Lesser Slave River.

6.0 EFFECTS OF ENGINEERING WORKS ON SEDIMENT PRODUCTION AND TRANSPORT

6.1 Description of Constructed Engineering Works

Of the five channels being specifically assessed in this study (South Heart, East Prairie, West Prairie, Swan and Driftpile Rivers), only the Driftpile River has remained in a relatively natural state. Extensive engineering works have been undertaken in all the remaining channels. A brief summary of works constructed to date in each channel follows.

6.1.1 East Prairie River

The East Prairie and West Prairie Rivers have undergone the most intensive engineering interventions. Flood control works were undertaken in the East Prairie River channel in 1962, when a 1370 metre long reach of the river downstream of the Highway 2 crossing was channelized. Similar works continued until 1971, at which time a total of 14,170 metres of the East Prairie River channel between Highway 2 and the South Heart River confluence had been channelized.

The extreme downstream end of the channelized section, originally constructed in 1966, progressively infilled and became completely blocked by sediment during the floods of June and July, 1983 (AENV, 1988). A flood relief channel was constructed in 1984 and was itself almost completely infilled and blocked by debris jams during the 1986 and 1988 flood events. Following the 1988 flood, the East Prairie River was diverted east through a diversion channel into the Traverse Creek watershed. The East Prairie River channel now drains directly into the channel connecting Buffalo Bay and Lesser Slave Lake, although some flow still travels overland north to the South Heart River channel; this northerly overland flow represents approximately 30% of the total East Prairie River flow (AENV, 1988 and personal communication, Mr. Rod Burr, Alberta Environment, January 2005).

In 1977, two channel cutoffs were constructed upstream of the channelization works to reduce bank erosion and preserve two farmsteads.

Between 1978 and 1980, bank protection works were constructed at several locations along East Prairie River. A total of approximately 580 metres of river bed and bank protection were placed in three phases near the Northern Alberta Railways bridge. River bed armouring was placed along the East Prairie River channel at the locations shown in Figure 5 (verbal communication, Mr. Jim Choles, P.Eng., AENV).

6.1.2 West Prairie River and Lower South Heart River

Channelization work commenced in the West Prairie River in the High Prairie area in 1953 to alleviate flooding. Additional channelization works were undertaken in between 1967 and 1971, by which approximately 22 000 metres of West Prairie River and South Heart River between Highway 2 and the east end of Horse Lakes had been channelized. The flood control works included channel straightening, ditching and dyking (NHCL, 1983).

In the late 1970's and early 1980's, efforts were made to control bank erosion and the rate of bed degradation in the West Prairie River channel upstream of the confluence with South Heart River. A boulder grade control structure was constructed at the Highway 2 crossing. A second grade control structure was constructed at about Station 61+00 D/S (NHCL, 1984). Sheetpile groynes were constructed upstream of the railway crossing in 1979 and 1980. Approximately 900 metres of the channel downstream of the railway crossing were shaped and armoured with riprap between 1980 and 1982, and 75 metres of riprap bank protection was placed just upstream of the railway crossing in 1983.

Deposition in the lower reaches of the South Heart River occurred, likely as a result of deposition of sediment from East Prairie River (AENV, 1988). In 1983, a channel was constructed from the east end of the Horse Lakes complex to divert South Heart River around an infilled section of channel, rejoining the natural channel approximately 3 km downstream. By 1988, the lower reaches of South Heart River became completely infilled and the river breached the flood control dykes. The river was then diverted through the Horse Lakes delta/marsh area.

6.1.3 South Heart River Upstream of West Prairie River

The South Heart River channel has not been modified upstream of the confluence with the West Prairie River. A dam was constructed on the main stem of the channel in the 1950's to regulate water levels in Winagami Lake and to provide a domestic water supply for communities north and west of the lake. The dam provides some limited flood control but is reported to have a limited effect on the hydraulic characteristics of the downstream channel (AENV, 1988).

6.1.4 Swan River

In 1983, seven cut-offs were constructed along the Swan River channel northeast of Kinuso. The cutoffs were constructed for the purposes of flood control. Other additional engineering works constructed in the Swan River channel include pile and timber spurs, constructed to protect the Highway 2 bridge crossing in the late 1960's or early 1970's. Flood control dykes have been constructed at Kinuso and approximately 10 km northeast pf Kinuso, (the latter works were constructed around 1986).

6.1.5 Driftpile River

Channel modifications and flood control dyking have been proposed for the Driftpile River (Samide Engineering Ltd., 1996). To date, flood control dykes have been constructed, but no channel modifications or flood bypass channels have been constructed (e-mail communication, Mr. Rod Burr, P.Eng, Alberta Environment).

6.2 Channel Changes Since Implementation of Engineering Works

Channelization of the channels, such as in the East Prairie and West Prairie Rivers, or construction of channel cutoffs, such as in the Swan River, has reduced the overall length of the channels and increased the channel slopes. In response, the channels have attempted to increase their respective lengths by developing meanders, resulting in bank erosion. At the same time, the channels are increasing bed elevations along the lower reaches by depositing sediment (the process of aggradation) and lowering bed elevations in the upper reaches by downcutting (the process of degradation). Both meander bend development with the associated bank erosion and channel downcutting produce sediment, which the river moves downstream to deposit in the lower reaches.

The processes have been documented over time, especially in the East Prairie, West Prairie and South Heart River channels, which have been the subject of numerous studies. River engineering works in these channels have significantly increased sediment loads, which in the downstream reaches of these channels, particularly the East Prairie, West Prairie and South Heart Rivers, have contributed to greater rates and volumes of sediment deposition, reduced channel capacities and increased the frequency of overbank flow and flooding. These effects have largely negated the downstream flood protection benefits that these works were originally planned to provide.

Cross-sectional data provided by Alberta Environment were used to assess the volumes of sediment removed from the channels, through degradation and/or bank erosion, or deposited in the channels. The analyses were conducted for the East Prairie and West Prairie Rivers and were restricted by the limited availability of recent survey data as well as the limited overlap between surveys, as discussed in Section 3.2.2. Changes in channel area (enlargement or reduction) at sections with survey data for two or more survey dates were computed, and multiplied by channel lengths to obtain estimates of volumetric changes in the respective channels. The results of the channel volume change analyses are presented in Tables 11 and 12.

TABLE 11
Volumetric Changes in East Prairie River

Section	Channel Area in Survey Year (m^2)			Change in Sediment Volume Between Survey Dates (m^3)	
	1977	1989/1990	2000	1989 – 2000	1977 – 2000
1632+82 U/S	262.3	250.2		---	---
1046+74 U/S	152.5	143.9		---	---
600+00 U/S	213.0	296.3		---	---
490+26 U/S	215.5	384.9	201.4	-67,130	-5,150
360+00 U/S	243.3	264.9	409.4	45,940	52,800
281+70 U/S		336.4	531.1	65,480	---
139+30 U/S		444.2	539.2	28,320	---
86+00 U/S		360.4	464.3	10,360	---
73+90 U/S		655.1	579.1	-37,770	---

The comparative survey data for East Prairie River summarized in Table 11 are for sections located upstream of the Highway 2 crossing; no comparative data are available downstream of the crossing. Positive changes in sediment volume at Section 360+00 U/S indicate deposition, whereas a negative change in sediment volume at the next section upstream, 490+26 U/S, indicates channel enlargement. However, there are sufficient uncertainties in the survey data to prevent definitive conclusions from being drawn regarding the zones of bed degradation versus bed aggradation or regarding trends in the rate of change.

TABLE 12
Volumetric Changes in West Prairie and South Heart Rivers

Section	Channel Area in Survey Year (m^2)			Change in Sediment Volume Between Survey Dates (m^3)	
	1976/1977	1982-1984	1991/1992	1982 – 1992	1977 – 1992
687+06 U/S	139.8		154.4		8,940
541+96 U/S	146.6		130.3		-8,710
336+60 U/S	170.1		170.3		90
178+50 U/S	158.5		189.3		1,990
161+49 U/S	210.9		268.1		3,930
133+40 U/S	170.5		279.5		16,000
40+00 U/S	182.5		403.0		11,800
20+00 U/S	204.9		178.8		-800
10+00 U/S	154.2		219.9		11,000
210+00 D/S		102.8	98.5	-1,050	
250+00 D/S		114.6	103.5	-1,020	
270+00 DS		143.9	134.6	-420	
280+00 D/S		159.7	140.6	-550	
289+00 D/S		131.1	114.1	-470	

The most recent survey data for the West Prairie and South Heart River were gathered in 1991 and 1992. At that point in time, the data summarized in Table 12 indicate generalized channel enlargement (loss of material) downstream of Highway 2 and deposition upstream of Highway 2. This observation conflicts with earlier studies that document bed aggradation downstream of Station 200+00 D/S and bed degradation and channel enlargement upstream of Station 200+00. Again, there is sufficient uncertainty with respect to both the survey datums and the comparability of the sequential survey data sets to necessitate caution in applying these results to further analyses.

6.3 Comparison with Estimated Natural Channel Changes

Natural degradation in the East Prairie and West Prairie River channels has been caused by base level changes resulting from the lowering of Lesser Slave Lake (Hydrocon, 1984). This "natural" bed degradation is an ongoing process that is distinct from the channel changes (degradation and aggradation) that have resulted over the past 100 years as a result of human activity.

Outhet (Alberta Environment, 1977) estimated that approximately half of the total suspended sediment load in the East Prairie and West Prairie Rivers, or approximately 349,000 tonnes per year, resulted from "natural" sources. The total annual suspended sediment load in the East Prairie and West Prairie Rivers determined in this study is 1,130,000 tonnes per year. Hence, Outhet's estimate of natural source sediment load (349,000 tonnes per year) represents only 30% of the present computed load, down from approximately 50% in 1977. Hence, the proportion of the total sediment load resulting from channel changes and changes in sediment production in the watersheds as a result of land use changes has increased relative to the proportion of sediment generated by natural sources.

7.0 EFFECTS OF LAND USE ACTIVITIES ON SEDIMENT PRODUCTION

7.1 Land Use Changes in the Lesser Slave Lake Watershed

The sub-catchments within the Lesser Slave Lake drainage basin have been impacted by various anthropogenic changes. To reflect these changes and account for associated potential increases in sediment yield, the sub-catchments were organized into 5 distinct land use categories. This was done by conducting a GIS-based analysis of 2003 digital satellite imagery. The land use categories were:

- woodland/undisturbed
- municipal/urban
- cleared/logging
- agriculture
- gravelled (roads and well pads)

For each of the five major rivers flowing into Lesser Slave Lake, land uses within the respective watersheds were visually identified from 2003 satellite images and measured via GIS analysis. The results are summarized in Table 13.

TABLE 13
2003 Land Use Areas in Sub Basins

Land Use	Land Use Area in Sub-Basin (hectares)				
	East Prairie	West Prairie	South Heart	Swan	Driftpile
Municipal/Urban	40	299	566	471	14
Cleared / Logging	9,424	8,944	8,833	24,240	12,739
Agriculture	18,240	42,039	76,431	18,071	14,450
Gravelled (Roads and Well Pads)	1,254	1,138	2,776	3,750	480
Total Disturbed Area	28,958	52,420	88,606	46,532	27,683
Woodland / Undisturbed	129,240	88,450	209,775	176,029	57,865
Total Basin Area (at Mouth)	158,198	140,870	298,381	222,561	85,548

Development in the watersheds, and corresponding areas of disturbance, has been increasing since the area was first settled more than 100 years ago. Agriculture, oil and gas exploration and development, forestry and urbanization have all increased. Increased surficial disturbances have the potential for increased erosion and higher sediment yields to the channels. The historical increases in land disturbance are shown in Figure 12.

7.2 Estimated Impacts of Land Use Changes on Sediment Production

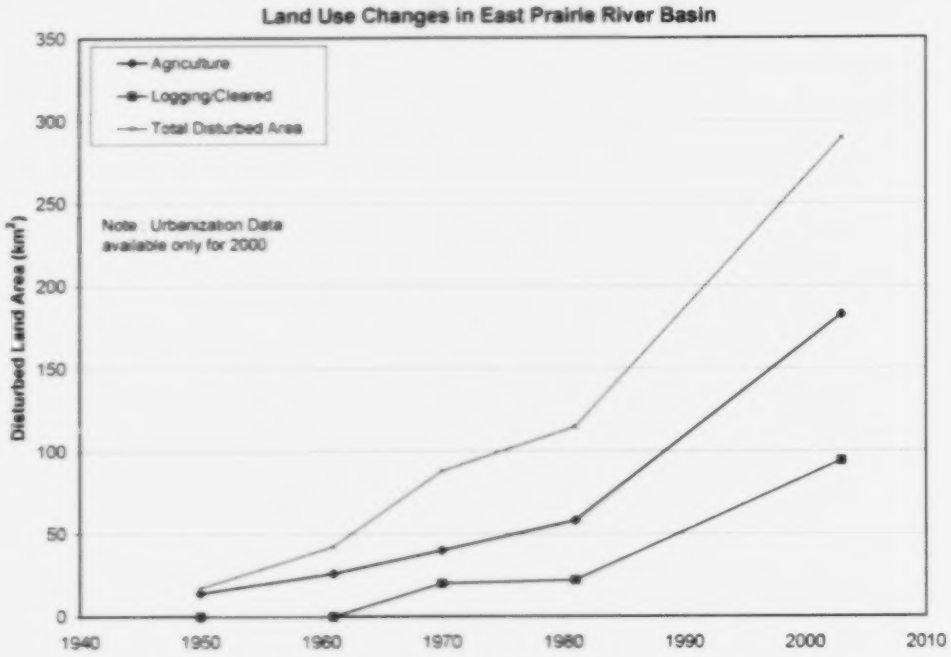
Soil loss and the rate of denudation is a function of several factors, including land use, soil type and erodibility, vegetative cover, and ground slope. The impacts of land use, for example, on soil loss and sediment production are demonstrated by the typical soil loss rates presented in Table 14 (as presented in Alberta Environment, 2004).

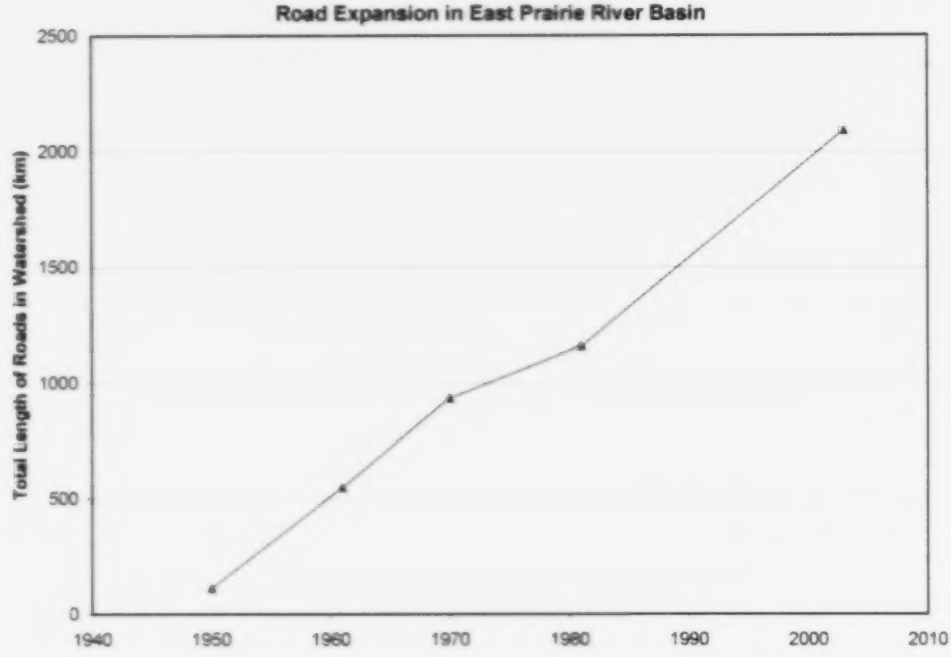
TABLE 14
Soil Loss for Various Land Uses

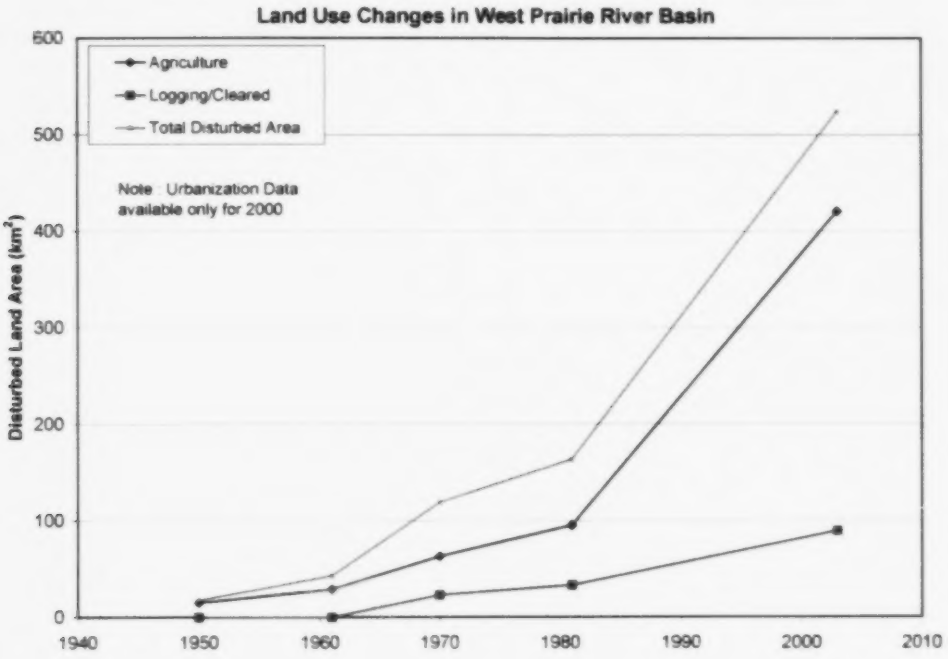
Land Use	Soil Loss/Rate of Denudation (tonnes/year/hectare)
Agriculture	18.7
Cleared / Logging	3.5
Urbanized	2.9
Gravelled	18.8
Woodland / Undisturbed	1.0

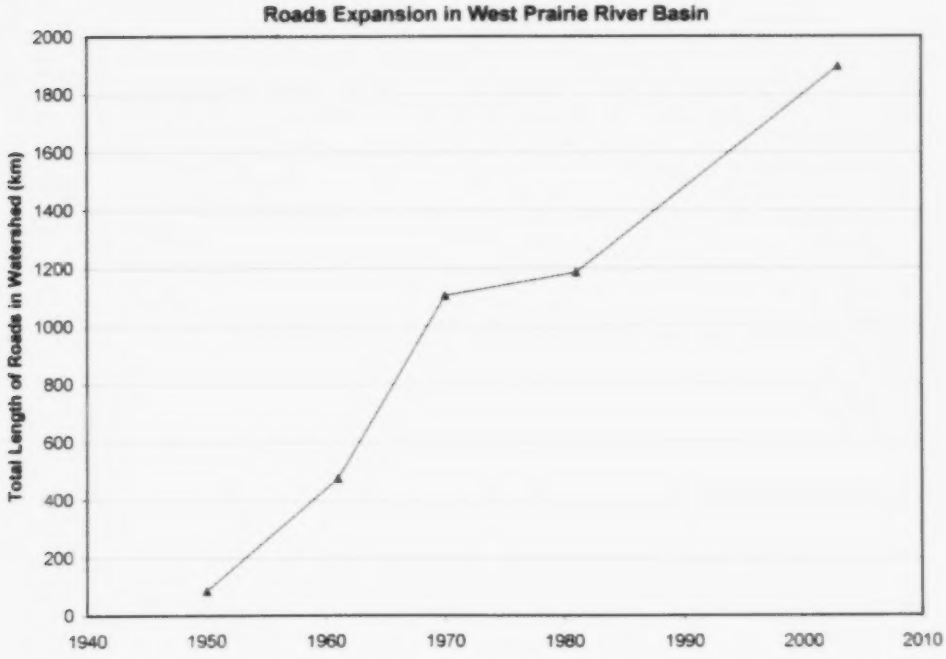
Other studies, such as the Tri-Creeks watershed in Alberta, have assessed the impacts of specific land uses such as logging on sediment production. The Tri-Creeks study found that constructing a haul road and logging 40% of the land area in one of the study basins resulted in a 200% increase in the in-stream sediment load (Bodnaruk, 1987), which was equivalent to an increase in sediment yield of approximately 5 tonnes/km^2. The Tri-Creeks study was conducted over a period of 17 years, of which the first 5 years were for baseline/natural conditions, the next 10 years for post-road construction and harvesting conditions, and the final 2 years were for the post-harvest period. Harvesting took place over a period of 7 years between 1977 and 1983.

There are no generally applicable factors relating land use and rate of denudation to in-stream sediment loads. The Universal Soil Loss Equation can be used to estimate sediment yield based on these and other variables, but it is outside the scope of the present study to apply this method to the watersheds tributary to Lesser Slave Lake. Nevertheless, based on the rate of land development demonstrated in Figure 12, and the increased soil losses for disturbed areas given in Table 14, there is little doubt that increased human activity in the watersheds draining to Lesser Slave Lake is resulting in increased sediment loads in the affected channels.


Land Use Changes in East Prairie River Basin
Agriculture
Logging/Cleared
Total Disturbed Area
Note : Urbanization Data
available only for 2000
Disturbed Land Area (km²)
350
300
250
200
150
100
50
0
1940
1950
1960
1970
1980
1990
2000
2010


Road Expansion in East Prairie River Basin
Total Length of Roads in Watershed (km)
2500
2000
1500
1000
500
0
1940
1950
1960
1970
1980
1990
2000
2010





amec Earth & Environmental

CLIENT: ALBERTA ENVIRONMENT

PROJECT: LESSER SLAVE LAKE SEDIMENT STUDY

TITLE: LAND USE CHANGES IN EAST AND WEST PRAIRIE RIVER BASINS

DATE:	JOB No.:	CAD FILE:	FIGURE No.:	REV
MARCH 2005	CW1902	1902-S00.dwg	FIGURE 12	A

8.0 SUMMARY AND CONCLUSIONS

Alberta Environment posed a number of questions in their Terms of Reference for this study. These questions are specifically addressed below.

What are the major natural and human influenced sources of sediment in the Lesser Slave Lake watershed?

Sediment is produced by three major mechanisms in the Lesser Slave Lake watershed. These are:

- sediment resulting from "natural" processes such as downcutting of the channels resulting from post-glaciation lowering of Lesser Slave Lake as well as from soil erosion from undisturbed areas;
- sediment resulting from the response of the river channels to man-made flood control, erosion control and river training works; i.e. bank protection, channelization and dyking projects; and
- sediment resulting from the land use changes and altered runoff characteristics in the watershed. These include logging, agriculture, oil and gas development, urban development and roads.

What are their relative contributions to the total sediment load produced in the watershed?

The answer to this question can, on the basis of the available data, only be answered qualitatively. Outhet (Alberta Environment, 1977) apportioned the total sediment load entering the Horse Lakes/ Buffalo Bay complex to natural sources (50%), channelization (49%) and agriculture (1%).

The channel survey data available for this study do not provide sufficient detail to determine whether channel degradation and aggradation rates are increasing, remaining the same or declining from the levels assessed by Outhet and others. Recent (i.e. post 1992) data are available only for a short section of the East Prairie River. Specific gauge curves developed for the present study indicate that channel bed levels have remained relatively stable in the West Prairie River near High Prairie (WSC Station 07BF002) and in the East Prairie River near Enilda (WSC Station 07BF001) since 1982 and 1976, respectively. However, the specific gauge curves reflect conditions at only a single point along the channels. Comparative thalweg profiles show some surprising results, including apparent bed aggradation in East Prairie River from approximately Station 490+26 U/S to Station 1632+828 U/S, a zone that was previously determined to be degrading. Hence, it is not possible to state with certainty whether sediment loads resulting from channel interventions are increasing or decreasing.

It is known that the areas of disturbance in each of the watersheds have increased dramatically over the past 50 years. The total disturbed land area in the East Prairie River basin is 17 times the area of disturbance 50 years ago, and in the West Prairie River basin is 30 times the area of disturbance 50 years ago. Although the increased sediment loads resulting from land disturbance have not been quantified in this study, it is reasonable to state that sediment loads are expected to have increased as a result of land use changes. On the basis of increased area of disturbed lands, sediment generation from disturbed lands may have increased by approximately 300%.

Based on the above, we believe that sediment loads as a result of natural channel processes have likely decreased, primarily as a result of reduced areas of undisturbed lands and possible upstream extension of the zone affected by channel modifications. Sediment yields from disturbed lands certainly have increased. It is uncertain whether the sediment loads resulting from channel modifications have increased, remained the same, or decreased since the last studies were undertaken in the mid-1980's.

What is the fate of sediment generated from these sources? How much sediment is deposited in the lake itself, and how much is deposited in other areas?

A sediment balance was prepared for the Lesser Slave Lake. It is estimated that 85% of the sediment carried by the East Prairie, West Prairie and South Heart Rivers is deposited within the Horse Lakes and Buffalo Bay areas. Although East Prairie River now skirts the south edge of Buffalo Bay and flows directly into the channel connecting Buffalo Bay with Lesser Slave Lake, overbank flooding is believed to result in a similar proportion (approximately 85%) of the sediment to be deposited upstream of the Buffalo Bay outflow, as in the West Prairie River upstream of Buffalo Bay. For the Swan and Driftpile Rivers and ungauged basins flowing into the lake, most to all of the sediment conveyed by these channels will be deposited within the lake. The total annual net sediment input to Lesser Slave Lake is computed to be approximately 1,170,000 tonnes. The amount deposited in the Buffalo Bay/Horse Lakes area is computed to be 1,100,000 tonnes per year.

How much sediment moves through the system into Lesser Slave River?

Sediment data gathered downstream of the outlet from Lesser Slave Lake cannot be used to directly estimate sediment outflows from the lake, as channel modifications between the lake and the sediment monitoring station are resulting in bank erosion and local sediment production. The trap efficiency of Lesser Slave Lake was therefore used to estimate the sediment outflow to Lesser Slave River. At least 97% of the inflowing sediment is estimated to settle in Lesser Slave Lake. Hence, the annual sediment output from the lake to Lesser Slave River is approximately 36,000 tonnes (as compared to a measured average annual sediment load of 44,200 tonnes in the Lesser Slave River at the mouth).

What is the present rate of sedimentation in the lake and in other depositional areas?

The present rate of sedimentation in Lesser Slave Lake is approximately 1,170,000 tonnes per year. Much of the sediment deposited in Lesser Slave Lake settles out on the deltas formed at the mouths of the Swan and Driftpile Rivers. Growth rates for the Swan and Driftpile River deltas were determined to be approximately 3.7 metres per year at the Driftpile River delta and 30 metres per year at the Swan River delta.

How do current rates of sedimentation compare with historical rates of sedimentation?

Sedimentation in Lesser Slave Lake is a function of the sediment produced within the watershed, the sediment-carrying capacity of the channels and the erosion from or deposition within or adjacent to the channels en route to the lake.

Development within the watersheds is certainly increasing the sediment generated within the basins, primarily in those basins on the south side of the lake. Most of the sediment generated from these basins is fine-grained and will be conveyed by the channels as wash load.

Assessments of discharges in the channels indicate that there are no significant changes in the higher end of the flow spectrum of the channels. Hence, there are no significant changes to the sediment-carrying capacity of the channels from a hydrologic standpoint.

For those streams draining into Buffalo Bay at the west end of Lesser Slave Lake, sediment deposition within, and adjacent to, the channels is occurring, which reduces the amount of sediment reaching Buffalo Bay and consequently Lesser Slave Lake. South Heart River has been routed through Horse Lakes since 1984, which is believed to have increased the amount of sediment deposited upstream of Buffalo Bay and reduced the amount of sediment reaching the South Heart River delta in Buffalo Bay. Sediment inputs to Buffalo Bay have also been reduced by the 1988 diversion of East Prairie River through the Traverse Creek watershed. In this case, it is not certain whether the volume of sediment reaching Lesser Slave Lake from the East Prairie River watershed has increased or remained the same; for this study it was assumed to have remained the same. Based on these factors, it is believed that sediment delivery to Buffalo Bay has been reduced from pre-1984 levels, but data to support this conclusion have not been gathered.

There is insufficient data to allow a quantitative comparison between present and historical rates of sedimentation on the respective river deltas and in Lesser Slave Lake, as there are limited suspended sediment data available in the tributary watersheds for the period of 1983 to 1997 and no data available since 1997. The available data are not sufficient to determine whether channel changes as a result of man-made activities are ongoing, to what extent land use changes in the watersheds are affecting sediment loads in the channels, or how the estimated annual sediment loads are apportioned between "natural" sources, man-made channel changes and land use changes.

What are the potential future impacts of the current rates of sedimentation on the lake?

At the present rate of sedimentation, it would take more than 10,000 years to fill in Lesser Slave Lake. At the present time, therefore, Lesser Slave Lake is considered to be at a low risk of impact due to sedimentation.

The sediment balance for Lesser Slave Lake could be altered if the Horse Lakes/Buffalo Bay area were to be infilled over time. The impacts on sedimentation in Lesser Slave Lake would depend on what path(s) the sediment-carrying flow within East Prairie, West Prairie and South Heart Rivers take into the lake. As the downstream channels become infilled, channel capacities are reduced and discharges are more likely to flow in the overbank areas. This reduces both depths and velocities of flow, resulting in a reduced sediment-carrying capacity, increased deposition and hence reduced sediment input to Lesser Slave Lake.

Over time, the impacts of man-made channel modifications upstream of the lake will be attenuated as the rivers approach regime conditions; this will reduce sediment inputs to the channels. This reduction in sediment input will be offset to some degree by increased sediment loading as a result of land use changes. Because the present distribution of sediment based on origin cannot be well established, it is not possible to project future sedimentation rates to Lesser Slave Lake or estimate the impacts of future sedimentation on the lake.

Additional data are required to fully address the questions raised by Alberta Environment in the Terms of Reference.

Respectfully submitted,

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Permit to Practice Number: P 4546

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APPENDIX A

Bias Correction Factor

Bias Correction Factor Assessment

Bias is inherent to quantities estimated from rating curves fitted to logarithmically transformed series of data, in this case mean daily flow and suspended sediment concentration data sets. In the absence of a bias correction, substantial negative bias of predicted concentrations occurs over most flows (Cohn et al, 1989). The Quasi-Maximum Likelihood Estimator (QMLE; Cohn et al, 1989) was applied to account for the negative bias resulting from the rating curves. The QMLE is a correction based on the squared standard error of the regression residuals, expressed as:

$$Y = \exp(\frac{s^2}{2})$$

where s is the standard error (variance) of the regression residuals (Cohn et al, 1989).

Bias factors of 1.33, 1.56, 1.38, 1.58, and 1.68 were calculated for the East Prairie, West Prairie, Driftpile, Swan and Lesser Slave Rivers respectively. Applying the bias factors to the estimated sediment data results in an increase in predicted sediment, which registers as a small shift of the estimating rating curve due to the Log-Log data transformation.

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